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# ANALYSIS OF FINE AGGREGATE

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# I. Introduction

The purpose of this project was to determine, by petrographic analysis and other techniques, whether or not sands from 25 locations in New York State would be suitable for use as aggregate in the making of concrete. Among other considerations, of primary importance was the determination of the amount and type of deleterious materials present in each sample. This was accomplished by several methods: (1) The percent composition, by constituents, of each size fraction of each sample, (2) the identification of clay minerals by x-ray analysis and (3) an acid insoluble residue analysis of the limestone portion of samples containing greater than 10 percent limestone. Also included are roundness and sphericity measurements and the identification of the types of minerals and rocks which were classified as miscellaneous.

These 25 sands were received as 8 graded size fractions (a few samples have only 7 fractions) ranging from (-3/8 +4) to (-200) mesh. The following list gives the location and number of fractions received of each sample.

| Sand No. | Source | |
|---|---|---|
| 1 | Long Island | All sizes present |
| 2 | Corinth | All sizes present |
| 3 | Boonville | All sizes present |
| 4 | Plattsburg | No (-3/8 +4) mesh fraction |
| 5 | Oak Orchard | All sizes present |
| 6 | Irving | All sizes present |
| 7 | Franklinville | No (-3/8 +4) |
| 8 | Corning | All sizes present |
| 9 | Clarence | All sizes present |
| 10 | Watertown | No (-3/8 +4) |
| 11 | Fulton | All sizes present |
| 12 | Penfield | All sizes present |
| 13 | Vandalia | No (-3/8 +4) |
| 14 | Clifton Springs | All sizes present |
| 15 | Sherburne | No (-3/8 +4) |
| 16 | Bath | All sizes present |
| 17 | Cohocton | No (-3/8 +4) |
| 18 | Hudson | All sizes present |
| 19 | Caledonia | No (-3/8 +4) |
| 20 | Bethlehem | All sizes present |
| 21 | Dunn's Bank | All sizes present |
| 22 | Port Jervis | All sizes present |
| 23 | Mechanicville | All sizes present |
| 24 | Binghamton | All sizes present |
| 25 | Owego | All sizes present |

## II. Procedure

The procedures followed throughout the course of this analysis conform to ASTM designation C-295, with the following additions:

1. Acid insoluble residue analysis of limestone fraction.
2. Roundness and sphericity measurements.
3. Clay mineral identification by x-ray analysis.

A. (-3/8 +4) and (-4 +8) mesh fractions

why different treatment between these two and not smaller sizes?

These fractions were separated into their constituents by examination with a stereoscopic binocular microscope and recorded as percent by weight. A visual description was made of these two fractions and comments made regarding particle shape, surface texture and other distinguishing characteristics. An x-ray analysis, using a spectrogoniometer, was done on the shale and siltstone portions to identify the types of clay minerals present. The rock types included in the miscellaneous category were identified by the use of stereoscopic binocular and petrographic microscopes.

no. of particles?

?

type of diffractometer

B. (-8 +14) to (-100 +200) mesh fractions

A grain count was made, using a stereoscopic binocular microscope (petrographic microscope on (-100 +200) mesh fraction) to determine the percentage of each constituent in each fraction. A visual description was made of the size fractions (-8 +14) to (-48 +100) mesh as a whole, noting color, particle shape, noticeable rock or mineral

types and other distinguishing characteristics. Minerals included in the miscellaneous category were identified by examination with stereoscopic binocular and petrographic microscopes.

In the (-3/8 +4) and (-4 +8) mesh sizes, the miscellaneous category is mainly composed of and reported as rock types, while in the (-8 +14) to (-100 +200) mesh sizes, the rock types have, in general, broken down into their mineral constituents and are reported as such.

## C. -200 mesh fraction

The -200 mesh size was separated into clay and silt fractions by allowing the silt fraction to settle out of a water suspension. This clay suspension (-10 micron particle size) was dried, and a random x-ray pattern run indicating those minerals present. The silt fraction was also dried and a portion made into a collodian slide which was also examined by x-ray diffraction. The remainder of the -10 micron clay fraction was deflocculated, and a suspension siphoned off containing particles less than 4 microns in size. This suspension was dried, and an oriented x-ray pattern was made to determine the clay minerals present.

Significance? How much clay mineral?

## D. Acid insoluble residue of limestone

If limestone was present in any sample in an amount greater than 10 percent, a 10-gram portion was taken from the (-3/8 +4) and (-4 +8) mesh sizes, dissolved in hydrochloric acid, and the percentage of acid insoluble residue was determined. These percentages could then be compared with available sulfate-soundness data to give an indication of the stability of the limestone present.

structural integrity?

E. Roundness and sphericity measurements

Quantitative sphericity measurements, using a petrographic microscope and camera lucida, were done on 100 grains taken at random from the (-14 +28) size fraction. The grains were placed on an ordinary

25 at a time ?

glass slide and 25 grains lying on their maximum projection area were moved to the edge of the slide and fixed with adhesive cement. With the use of a camera lucida, the outline of the maximum projection area was traced from which the maximum dimension "a" could be measured, and, perpendicular to "a", the widest dimension "b" could be found. The slide was then turned on edge and the outline of the minimum projection area was traced. The widest dimension (or maximum thickness) "c", perpendicular to "a" could then be measured. Figure 1 illustrates, using a sample grain, the outline obtained and the orientation of "a", "b" and "c".

The ratios b/a and c/b were then calculated for each grain, from which a value of sphericity was obtained from a graph such as is shown in Figure 2.

Sphericity, b/a and c/b values were added and divided by the number of grains measured and reported as average values. A histogram was made giving the number of grains in each sphericity range (.4 to .5, .5 to .6, etc.).

Roundness measurements, which were qualitative only, were made on the same grains. A technique was used whereby a visual estimation by grouping was obtained as follows:

| | | Roundness value |
|---|---|---|
| Angular | - all edges sharp | 0 |
| Subangular | - < 50% of edges smooth | 33 |
| Subrounded | - > 50% of edges smooth | 66 |
| Rounded | - all edges smooth | 100 |

Each grain was given a roundness value according to the percentage of smooth edges. The number of grains in each group was multiplied by the roundness value for the group and the total divided by the number of grains giving an average roundness for the sample.

Should this not be based on the degree of roundness rather than whether rounded or not?

## III. Results

The results of this analysis are reported under four headings:

A. Percent composition by constituents

(1) (-3/8 +4) and (-4 +8) mesh sizes

(2) (-8 +14) to (-100 +200) mesh sizes

(3) -200 mesh size

B. Visual description of sample

C. Roundness and sphericity measurements

D. Acid insoluble residue analysis of limestone portion

### A. Percent Composition by Constituents

In the (-3/8 +4) and (-4 +8) mesh size ranges, the samples were arranged into five general categories depending on their outstanding constituent. Samples 5, 7, 11, 12, 13, 14, 17, and 19 contained a large percentage of sandstone, with lesser amounts of limestone and miscellaneous rocks. An appreciable amount of chert was noted in Sample 13. Miscellaneous rocks predominated in Samples 1, 2, 3, and 4 with Sample 3 having a large amount of limestone. A small amount of mica was observed in the (-4 +8) mesh size of Sample 1. Major amounts of siltstone and shale and lesser quantities of sandstone were found in Samples 8, 9, and 21. Limestone appeared in a small quantity in Sample 9, and Sample 8 contained an appreciable amount of chert. Sample 21 contained a large quantity of miscellaneous rocks. In Samples 10 and 15, limestone was the major constituent. Sample 10 also contained a large

amount of miscellaneous rocks, and sandstone was present in Sample 15 in an appreciable quantity. The remaining samples contained approximately equal portions of sandstone, siltstone, and shale with varying amounts of other constituents, such as limestone in Sample 20 and miscellaneous rocks in Samples 22 and 23.

Quartz and quartzite were included in the miscellaneous category of all samples. Other stable minerals and rocks classified as miscellaneous were feldspar, garnet, ilmenite, granite, and gneiss.

Constituent percentages in the two coarse fractions of each sample are listed in Table I.

Can this info be tabulated in % by number of particles also? What was total number counted?

Table I. Lithologic Compositions of the Samples in the (-3/8 +4) and (-4 +8) Size Fractions, % by weight

| Size Fraction | Shale & siltstone | Sandstone | Limestone | Misc.* (QTZ) | Chert |
|---|---|---|---|---|---|
| **Sample No. 1** | | | | | |
| -3/8 +4 | 0.2 | 0.6 | ---- | 99.2 | ---- |
| -4 +8* | 1.1 | 5.5 | ---- | 90.9 | ---- |
| **Sample No. 2** | | | | | |
| -3/8 +4 | ---- | ---- | ---- | 100.0 | ---- |
| -4 +8 | ---- | 2.0 | ---- | 98.0 | ---- |
| **Sample No. 3** | | | | | |
| -3/8 +4 | ---- | ---- | 30.0 | 70.0 | ---- |
| -4 +8 | ---- | 2.6 | 32.5 | 64.9 | ---- |
| **Sample No. 4** | | | | | |
| no fraction | ---- | ---- | ---- | ---- | ---- |
| -4 +8 | 2.1 | 17.3 | 0.6 | 79.8 | ---- |
| **Sample No. 5** | | | | | |
| -3/8 +4 | ---- | 68.9 | ---- | 31.0 | ---- |
| -4 +8 | ---- | 67.6 | 12.2 | 19.8 | ---- |
| **Sample No. 6** | | | | | |
| no fraction | ---- | ---- | ---- | ---- | ---- |
| -4 +8 | 47.5 | 33.5 | ---- | 11.1 | 8.1 |
| **Sample No. 7** | | | | | |
| no fraction | ---- | ---- | ---- | ---- | ---- |
| -4 +8 | 0.8 | 75.5 | 3.9 | 12.4 | 7.6 |
| **Sample No. 8** | | | | | |
| -3/8 +4 | 75.0 | ---- | 1.8 | 9.1 | 13.9 |
| -4 +8 | 40.7 | 38.3 | 1.6 | 6.8 | 12.8 |

RECORDED AS 99.9%

% quantity

major constituents by %

separate by lith from chert

weight with both field grad and lab gradations;

* DETERMINE QUANT. OF QTZ AND INCLUDE ... DUE THIS ... GRATIVES FOR ... SAND.

Table I. (continued)

| Size Fraction | Shale & siltstone | Sandstone | Limestone | Misc. | Chert |
|---|---|---|---|---|---|
| | | Sample No. 9 | | | |
| -3/8 +4 | 75.9 | 2.5 | 11.4 | 9.2 | 0.9 |
| -4 +8 | 12.5 | 31.7 | 41.5 | 12.7 | 1.6 |
| | | Sample No. 10 | | | |
| no fraction | ---- | ---- | ---- | ---- | ---- |
| -4 +8 | 3.2 no clay | 10.7 | 65.5 | 19.8 | ---- |
| | | Sample No. 11 FULTON | | | |
| -3/8 +4 | ---- | 91.0 | 2.3 | 6.8 | ---- |
| -4 +8 | ---- | 95.0 | 2.6 | 3.4 | ---- |
| | | Sample No. 12 | | | |
| -3/8 +4 | ---- | 81.3 | 11.1 | 7.6 | ---- |
| -4 +8 | ---- | 79.9 | 10.5 | 9.6 | ---- |
| | | Sample No. 13 | | | |
| no fraction | ---- | ---- | ---- | ---- | ---- |
| -4 +8 | 9.6 | 61.1 | 3.1 | 11.2 | 14.6 |
| | | Sample No. 14 | | | |
| -3/8 +4 | ---- | 62.0 | 32.4 | 10.8 | 0.1 |
| -4 +8 | ---- | 67.3 | 24.7 | 7.4 | 0.3 |
| | | Sample No. 15 | | | |
| no fraction | ---- No | ---- | ---- | ---- | ---- |
| -4 +8 | 14.2 X-ray | 34.0 | 45.2 | 2.7 | 3.4 |
| | | Sample No. 16 BATH | | | |
| -3/8 +4 | 30.6 | 35.6 | 21.0 | 7.9 | 3.0 |
| -4 +8 | 30.6 | 50.8 | 10.5 | 5.5 | 2.6 |

Table I. (continued)

| Size Fraction | Shale & siltstone | Sandstone | Limestone | Misc. | Chert |
|---|---|---|---|---|---|
| | | Sample No. 17 | | | |
| no fraction | ---- | ---- | ---- | ---- | ---- |
| -4 +8 | 4.1 | 85.3 | 1.8 | 4.0 | 4.4 |
| | | Sample No. 18 | | | |
| -3/8 +4 | 43.4 | 31.2 | 7.4 | 15.9 | ---- |
| -4 +8 | 59.8 | 33.2 | 1.6 | 7.4 | ---- |
| | | Sample No. 19 CALEDONIA | | | |
| no fraction | ---- | ---- | ---- | ---- | ---- |
| -4 +8 | 3.7 | 68.9 | 17.4 | 7.8 | 1.6 |
| | | Sample No. 20 | | | |
| -3/8 +4 | 43.7 | 31.8 | 13.3 | 10.0 | 0.1 |
| -4 +8 | 41.4 | 41.5 | 12.4 | 3.8 | 0.1 |
| | | Sample No. 21 | | | |
| -3/8 +4 | 30.0 | 30.7 | 2.6 | 35.4 | 0.6 |
| -4 +8 | 62.9 | 25.8 | 2.5 | 6.6 | 0.8 |
| | | Sample No. 22 | | | |
| -3/8 +4 | 47.9 | 34.5 | ---- | 14.9 | 0.8 |
| -4 +8 | 38.6 | 44.7 | 0.2 | 15.2 | 0.8 |
| | | Sample No. 23 | | | |
| -3/8 +4 | 31.4 | 31.5 | 1.2 | 28.3 | 2.3 |
| -4 +8 | 46.0 | 33.8 | 0.4 | 18.8 | 0.7 |
| | | Sample No. 24 BINGHAMPTON | | | |
| -3/8 +4 | 8.2 | 56.5 | 19.9 | 7.7 | 5.9 |
| -4 +8 | 11.5 | 57.7 | 18.4 | 3.7 | 8.4 |

Table I. (continued)

| Size Fraction | Shale & siltstone | Sandstone | Limestone | Misc. | Chert |
|---|---|---|---|---|---|
| | | Sample No. 25 OWEGO | | | |
| -3/8 +4 | 16.3 | 42.4 | 29.4 | 7.3 | 2.3 |
| -4 +8 | 20.2 | 55.5 | 15.4 | 2.7 | 6.5 |

* The (-4 +8) fraction contains 2.0% mica.

Table II gives the percent composition by constituents of all 25 samples in the size fractions from (-8 +14) mesh through (-100 +200) mesh. Individual mineral grains of quartz and feldspar became more numerous as the grain size became smaller, as might be expected when the granite and gneiss rocks are broken down into small fragments. In the case of the (-100 +200) fractions, a little less quartz and feldspar were found when more particles were put into the miscellaneous classification.

The miscellaneous category contained such minerals as magnetite, hornblende, garnet, ilmenite, augite, biotite, muscovite, and chlorite. Samples 1 and 2 contained larger amounts of mica; so these minerals were separated from the miscellaneous classification and listed in a special subdivision.

Samples 6, 9, 16, 18, 20, 21, 22, and 23 contained excessive amounts of siltstone and shale.

Large amounts of limestone fragments were found in Samples 9, 10, 14, 15, 19, and 25.

Chert was present in amounts over 10 percent in Samples 6, 7, 8, 13, 24, and 25.

Percent by weight was also asked for —

Table II. Compositions of the Samples From
(-8 +14) to (-100 +200) Size Fractions
(In % of Total No. of Grains)

why lumped together

Carbonates?

| Size Fraction | Feldspar & Quartz | | Sandstone | | Siltstone & Shale | | Misc. | | Limestone | | Chert | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Grains | % | Grains | % | Grains | % | Grains | % | Grains | % | Grains | % | |
| | | | | | Sample No. 1* | | | | | | | | |
| -8 +14 | 1976 | 94.1 | 105 | 5.0 | --- | ---- | ---- | ---- | ---- | ---- | --- | ---- | |
| -14 +28 | 1989 | 94.7 | 21 | 1.0 | --- | ---- | granite & gneiss 6 | 0.3 | ---- | ---- | --- | ---- | quartz & sand |
| -28 +48 | 1953 | 93.0 | 21 | 1.0 | --- | ---- | 27 | 1.3 | ---- | ---- | --- | ---- | |
| -48 +100 | 1890 | 90.0 | 36 | 1.7 | --- | ---- | 92 | 4.4 | ---- | ---- | --- | ---- | |
| -100 +200 | 1441 | 68.6 | 195 | 9.3 | --- | ---- | 309 | 14.7 | ---- | ---- | --- | ---- | |
| | | | | | Sample No. 2* | | | | | | | | |
| -8 +14 | 924 | 42.0 | 13 | 0.6 | --- | ---- | 1263 | 57.4 | ---- | ---- | --- | ---- | quartz & quartzite sand |
| -14 +28 | 1747 | 79.4 | 57 | 2.6 | --- | ---- | quartzite 385 | 17.5 | ---- | ---- | --- | ---- | |
| -28 +48 | 1824 | 82.9 | 7 | 0.3 | --- | ---- | 352 | 16.0 | ---- | ---- | --- | ---- | |
| -48 +100 | 1810 | 82.3 | 7 | 0.3 | --- | ---- | 306 | 13.9 | ---- | ---- | --- | ---- | |
| -100 +200 | 1613 | 73.3 | 99 | 4.5 | --- | ---- | 433 | 19.7 | ---- | ---- | --- | ---- | |
| | | | | | Sample No. 3 | | | | | | | | |
| -8 +14 | 1510 | 71.9 | 105 | 5.0 | --- | ---- | 160 | 7.6 | 325 | 15.5 | --- | ---- | |
| -14 +28 | 1737 | 82.7 | 12 | 0.6 | --- | ---- | quartzite 189 | 9.0 | 162 | 7.7 | --- | ---- | quartz & feldspar sand |
| -28 +48 | 1926 | 91.7 | 4 | 0.2 | --- | ---- | 103 | 4.9 | 67 | 3.2 | --- | ---- | |
| -48 +100 | 1890 | 90.0 | 12 | 0.6 | --- | ---- | 162 | 7.7 | 36 | 1.7 | --- | ---- | |
| -100 +200 | 1720 | 81.9 | 44 | 2.1 | --- | ---- | 233 | 11.1 | 103 | 4.9 | --- | ---- | |

Table II. (Cont.)

| Size Fraction | Feldspar & Quartz | | Sandstone | | Siltstone & Shale | | Misc. | | Limestone | | Chert | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Grains | % | Grains | % | Grains | % | Grains | % | Grains | % | Grains | % | |
| | | | | | Sample No. 4 | | | | | | | | |
| -8 +14 | 1362 | 68.1 | 484 | 24.2 | 64 | 3.2 | 90 | 4.5 | ---- | ---- | --- | ---- | |
| -14 +28 | 1796 | 89.8 | 86 | 4.3 | 48 | 2.4 | 70 | 3.5 | ---- | ---- | --- | ---- | granite & quartzite sand |
| -28 +48 | 1868 | 93.4 | 62 | 3.1 | 34 | 1.7 | 36 | 1.8 | ---- | ---- | --- | ---- | |
| -48 +100 | 1858 | 92.9 | 42 | 2.1 | --- | ---- | 100 | 5.0 | ---- | ---- | --- | ---- | |
| -100 +200 | 1764 | 88.2 | 134 | 6.7 | --- | ---- | 102 | 5.1 | ---- | ---- | --- | ---- | |
| | | | | | Sample No. 5 | | | | | | | | |
| -8 +14 | 463 | 24.4 | 973 | 51.2 | 120 | 6.3 | 97 | 5.1 | 247 | 13.0 | --- | ---- | |
| -14 +28 | 844 | 44.4 | 699 | 36.8 | 21 | 1.1 | 85 | 4.5 | 251 | 13.2 | --- | ---- | sandstone & quartz sand |
| -28 +48 | 1495 | 78.7 | 262 | 13.8 | 8 | 0.4 | 74 | 3.9 | 61 | 3.2 | --- | ---- | |
| -48 +100 | 1545 | 81.3 | 186 | 9.8 | 21 | 1.1 | 57 | 3.0 | 91 | 4.8 | --- | ---- | |
| -100 +200 | 834 | 43.9 | 302 | 15.9 | 102 | 5.4 | 350 | 18.4 | 312 | 16.4 | --- | ---- | |
| | | | | | Sample No. 6 | | | | | | | | |
| -8 +14 | 234 | 12.3 | 834 | 43.9 | 551 | 29.0 | 30 | 1.6 | ---- | ---- | 251 | 13.2 | sandstone & shale sand |
| -14 +28 | 629 | 33.1 | 555 | 29.2 | 530 | 27.9 | 38 | 2.0 | ---- | ---- | 148 | 7.8 | |
| -28 +48 | 1132 | 59.6 | 481 | 25.3 | 141 | 7.4 | 30 | 1.6 | ---- | ---- | 116 | 6.1 | |
| -48 +100 | 1062 | 55.9 | 469 | 24.7 | 80 | 4.2 | 177 | 9.6 | ---- | ---- | 112 | 5.9 | |
| -100 +200 | 769 | 40.5 | 631 | 33.2 | 230 | 12.1 | 154 | 8.1 | ---- | ---- | 116 | 6.1 | |
| | | | | | Sample No. 7 | | | | | | | | |
| -8 +14 | 155 | 8.6 | 997 | 55.4 | 261 | 14.5 | 20 | 1.1 | 146 | 8.1 | 221 | 12.3 | |
| -14 +28 | 472 | 26.2 | 722 | 40.1 | 191 | 10.6 | 30 | 1.7 | 257 | 14.3 | 128 | 7.1 | |
| -28 +48 | 815 | 45.3 | 632 | 35.1 | 92 | 5.1 | 42 | 2.3 | 158 | 8.8 | 61 | 3.4 | |
| -48 +100 | 1006 | 55.9 | 423 | 23.5 | 123 | 6.8 | 63 | 3.5 | 86 | 4.8 | 99 | 5.5 | |
| -100 +200 | 830 | 46.1 | 362 | 20.1 | 158 | 8.8 | 106 | 5.9 | 265 | 14.7 | 79 | 4.4 | |

Table II. (Cont.)

| Size Fraction | Feldspar & Quartz Grains | % | Sandstone Grains | % | Siltstone & Shale Grains | % | Misc. Grains | % | Limestone Grains | % | Chert Grains | % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Sample No. 8 | | | | | | | |
| -8 +14 | 113 | 5.4 | 1178 | 56.1 | 219 | 10.4 | --- | ---- | 69 | 3.3 | 521 | 24.8 |
| -14 +28 | 426 | 20.3 | 1094 | 52.1 | 74 | 3.5 | 38 | 1.8 | 63 | 3.0 | 405 | 19.3 |
| -28 +48 | 827 | 39.4 | 638 | 30.4 | 368 | 17.5 | 32 | 1.5 | 40 | 1.9 | 195 | 9.3 |
| -48 +100 | 1124 | 53.5 | 384 | 18.3 | 433 | 20.6 | 42 | 2.0 | 29 | 1.4 | 88 | 4.2 |
| -100 +200 | 1077 | 51.3 | 441 | 21.0 | 116 | 5.5 | 128 | 6.1 | 120 | 5.7 | 218 | 10.4 |
| | | | | | Sample No. 9 | | | | | | | |
| -8 +14 | 208 | 13.0 | 342 | 21.4 | 419 | 26.2 | 69 | 4.3 | 501 | 31.3 | 61 | 3.8 |
| -14 +28 | 475 | 29.7 | 375 | 23.4 | 230 | 14.4 | 40 | 2.5 | 406 | 25.4 | 74 | 4.6 |
| -28 +48 | 963 | 60.2 | 174 | 10.9 | 133 | 8.3 | 45 | 2.8 | 218 | 13.6 | 67 | 4.2 |
| -48 +100 | 1010 | 63.1 | 130 | 8.1 | 102 | 6.4 | 24 | 1.5 | 259 | 16.2 | 75 | 4.7 |
| -100 +200 | 771 | 48.2 | 102 | 6.4 | 10 | 0.6 | 133 | 8.3 | 584 | 36.5 | --- | ---- |
| | | | | | Sample No. 10 | | | | | | | |
| -8 +14 | 337 | 19.8 | 156 | 9.2 | 95 | 5.6 | --- | ---- | 1112 | 65.4 | --- | ---- |
| -14 +28 | 488 | 28.7 | 219 | 12.9 | 197 | 11.6 | 68 | 4.0 | 728 | 42.8 | --- | ---- |
| -28 +48 | 1013 | 59.6 | 134 | 7.9 | 112 | 6.6 | 31 | 1.8 | 410 | 24.1 | --- | ---- |
| -48 +100 | 1301 | 76.5 | 107 | 6.3 | 51 | 3.0 | 32 | 1.9 | 209 | 12.3 | --- | ---- |
| -100 +200 | 991 | 58.3 | 56 | 3.3 | 44 | 2.6 | 92 | 5.4 | 517 | 30.4 | --- | ---- |
| | | | | | Sample No. 11 | | | | | | | |
| -8 +14 | 122 | 8.1 | 1252 | 83.5 | 37 | 2.5 | 27 | 1.8 | 62 | 4.1 | --- | ---- |
| -14 +28 | 468 | 31.2 | 908 | 60.5 | 66 | 4.4 | 21 | 1.4 | 37 | 2.5 | --- | ---- |
| -28 +48 | 951 | 63.4 | 489 | 32.6 | 26 | 1.7 | 4 | 0.3 | 30 | 2.0 | --- | ---- |
| -48 +100 | 1224 | 81.6 | 207 | 13.8 | 21 | 1.4 | 27 | 1.8 | 21 | 1.4 | --- | ---- |
| -100 +200 | 1019 | 67.9 | 230 | 15.3 | 43 | 2.9 | 151 | 10.1 | 57 | 3.8 | --- | ---- |

Table II. (Cont.)

| Size Fraction | Feldspar & Quartz | | Sandstone | | Siltstone & Shale | | Misc. | | Limestone | | Chert | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Grains | % | Grains | % | Grains | % | Grains | % | Grains | % | Grains | % |
| | | | | | Sample No. 12 | | | | | | | |
| -8 +14 | 126 | 9.6 | 937 | 72.1 | 36 | 2.8 | 44 | 3.4 | 157 | 12.1 | --- | ---- |
| -14 +28 | 484 | 37.2 | 589 | 45.3 | 49 | 3.8 | 22 | 1.7 | 156 | 12.0 | --- | ---- |
| -28 +48 | 751 | 57.8 | 393 | 30.2 | 51 | 3.9 | 30 | 2.3 | 75 | 5.8 | --- | ---- |
| -48 +100 | 984 | 75.7 | 211 | 16.2 | 30 | 2.3 | 35 | 2.7 | 40 | 3.1 | --- | ---- |
| -100 +200 | 952 | 73.2 | 130 | 10.0 | 8 | 0.6 | 104 | 8.0 | 106 | 8.2 | --- | ---- |
| | | | | | Sample No. 13 | | | | | | | |
| -8 +14 | 104 | 8.0 | 884 | 68.0 | 25 | 1.9 | 8 | 0.6 | 5 | 0.4 | 274 | 21.1 |
| -14 +28 | 315 | 24.2 | 685 | 52.7 | 23 | 1.8 | 9 | 0.7 | --- | ---- | 268 | 20.6 |
| -28 +48 | 582 | 44.8 | 559 | 43.0 | 74 | 5.7 | 7 | 0.5 | --- | ---- | 78 | 6.0 |
| -48 +100 | 554 | 42.6 | 634 | 48.8 | 82 | 6.3 | 12 | 0.9 | --- | ---- | 18 | 1.4 |
| -100 +200 | 811 | 62.4 | 263 | 20.2 | 82 | 6.3 | 38 | 2.9 | --- | ---- | 106 | 8.2 |
| | | | | | Sample No. 14 | | | | | | | |
| -8 +14 | 153 | 10.9 | 702 | 50.1 | 109 | 7.8 | 42 | 3.0 | 379 | 27.1 | 15 | 1.1 |
| -14 +28 | 404 | 28.9 | 531 | 37.9 | 129 | 9.2 | 49 | 3.5 | 276 | 19.7 | 11 | 0.8 |
| -28 +48 | 756 | 54.0 | 301 | 21.5 | 99 | 7.1 | 24 | 1.7 | 206 | 14.7 | 14 | 1.0 |
| -48 +100 | 879 | 62.8 | 129 | 9.2 | 123 | 8.8 | 140 | 10.0 | 125 | 8.9 | 4 | 0.3 |
| -100 +200 | 960 | 68.6 | 98 | 7.0 | 112 | 8.0 | 104 | 7.4 | 116 | 8.3 | 10 | 0.7 |
| | | | | | Sample No. 15 | | | | | | | |
| -8 +14 | 46 | 3.8 | 676 | 56.3 | 31 | 2.6 | 14 | 1.2 | 391 | 32.6 | 42 | 3.5 |
| -14 +28 | 223 | 18.6 | 549 | 45.7 | 12 | 1.0 | 6 | 0.5 | 367 | 30.6 | 43 | 3.6 |
| -28 +48 | 415 | 34.6 | 433 | 36.1 | 22 | 1.8 | 25 | 2.1 | 293 | 24.4 | 12 | 1.0 |
| -48 +100 | 533 | 44.4 | 378 | 31.5 | 18 | 1.5 | 34 | 2.8 | 230 | 19.2 | 7 | 0.6 |
| -100 +200 | 461 | 38.5 | 268 | 22.3 | 64 | 5.3 | 14 | 1.2 | 323 | 26.9 | 70 | 5.8 |

Table II. (Cont.)

| Size Fraction | Feldspar & Quartz | | Sandstone | | Siltstone & Shale | | Misc. | | Limestone | | Chert | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Grains | % | Grains | % | Grains | % | Grains | % | Grains | % | Grains | % |
| | | | | | Sample No. 16 | | | | | | | |
| -8 +14 | 36 | 2.6 | 753 | 53.8 | 462 | 33.0 | --- | ---- | 90 | 6.4 | 59 | 4.2 |
| -14 +28 | 136 | 9.7 | 522 | 37.3 | 566 | 40.4 | --- | ---- | 116 | 8.3 | 60 | 4.3 |
| -28 +48 | 398 | 28.4 | 482 | 34.4 | 319 | 22.8 | --- | ---- | 122 | 8.7 | 76 | 5.4 |
| -48 +100 | 528 | 37.7 | 500 | 35.7 | 186 | 13.3 | 24 | 1.7 | 32 | 2.3 | 130 | 9.3 |
| -100 +200 | 385 | 27.5 | 587 | 41.9 | 181 | 12.9 | 35 | 2.5 | 127 | 9.1 | 85 | 6.1 |
| | | | | | Sample No. 17 | | | | | | | |
| -8 +14 | 54 | 4.9 | 895 | 81.4 | 45 | 4.1 | 10 | 0.9 | 11 | 1.0 | 85 | 7.7 |
| -14 +28 | 206 | 18.7 | 779 | 70.8 | 39 | 3.5 | 7 | 0.6 | 14 | 1.3 | 56 | 5.1 |
| -28 +48 | 480 | 43.6 | 436 | 39.6 | 134 | 12.2 | 9 | 0.8 | 22 | 2.0 | 20 | 1.8 |
| -48 +100 | 716 | 65.1 | 248 | 22.5 | 96 | 8.7 | 12 | 1.1 | 29 | 2.6 | --- | ---- |
| -100 +200 | 931 | 84.6 | 125 | 11.4 | 17 | 1.5 | 12 | 1.1 | 7 | 0.6 | 9 | 0.8 |
| | | | | | Sample No. 18 | | | | | | | |
| -8 +14 | 84 | 7.0 | 400 | 33.3 | 578 | 48.2 | 113 | 9.4 | 25 | 2.1 | --- | ---- |
| -14 +28 | 143 | 11.9 | 415 | 34.6 | 562 | 46.8 | 71 | 5.9 | 10 | 0.8 | --- | ---- |
| -28 +48 | 484 | 40.3 | 244 | 20.3 | 433 | 36.1 | 40 | 3.3 | --- | ---- | --- | ---- |
| -48 +100 | 482 | 40.2 | 319 | 26.6 | 371 | 30.9 | 28 | 2.3 | --- | ---- | --- | ---- |
| -100 +200 | 594 | 49.5 | 163 | 13.6 | 398 | 33.2 | 44 | 3.7 | --- | ---- | --- | ---- |
| | | | | | Sample No. 19 | | | | | | | |
| -8 +14 | 72 | 8.0 | 447 | 49.7 | 161 | 17.9 | 17 | 1.9 | 197 | 21.9 | 5 | 0.6 |
| -14 +28 | 166 | 18.4 | 468 | 52.0 | 145 | 16.1 | 10 | 1.1 | 106 | 11.8 | 5 | 0.6 |
| -28 +48 | 418 | 46.5 | 263 | 29.2 | 113 | 12.6 | 26 | 2.9 | 64 | 7.1 | 15 | 1.7 |
| -48 +100 | 615 | 68.3 | 130 | 14.4 | 85 | 9.4 | 28 | 3.1 | 40 | 4.4 | 4 | 0.4 |
| -100 +200 | 675 | 75.0 | 134 | 14.9 | 16 | 1.8 | 68 | 7.5 | 7 | 0.8 | --- | --- |

Table II. (Cont.)

| Size Fraction | Feldspar & Quartz | | Sandstone | | Siltstone & Shale | | Misc. | | Limestone | | Chert | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Grains | % | Grains | % | Grains | % | Grains | % | Grains | % | Grains | % |
| | | | | | Sample No. 20 | | | | | | | |
| -8 +14 | 59 | 5.4 | 649 | 59.0 | 189 | 17.2 | 50 | 4.5 | 153 | 13.9 | --- | ---- |
| -14 +28 | 108 | 9.8 | 572 | 52.0 | 261 | 23.7 | 54 | 4.9 | 106 | 9.6 | --- | ---- |
| -28 +48 | 333 | 30.3 | 391 | 35.5 | 228 | 20.7 | 61 | 5.5 | 88 | 8.0 | --- | ---- |
| -48 +100 | 403 | 36.6 | 411 | 37.4 | 186 | 16.9 | 45 | 4.1 | 55 | 5.0 | --- | ---- |
| -100 +200 | 402 | 36.5 | 469 | 42.6 | 181 | 16.5 | 32 | 2.9 | 17 | 1.5 | --- | ---- |
| | | | | | Sample No. 21 | | | | | | | |
| -8 +14 | 66 | 8.3 | 270 | 33.8 | 412 | 51.5 | 14 | 1.7 | 7 | 0.9 | 30 | 3.8 |
| -14 +28 | 180 | 22.5 | 217 | 27.1 | 396 | 49.5 | 5 | 0.6 | --- | ---- | 2 | 0.3 |
| -28 +48 | 436 | 54.5 | 113 | 14.1 | 238 | 29.8 | 13 | 1.6 | --- | ---- | --- | ---- |
| -48 +100 | 535 | 66.9 | 52 | 6.5 | 164 | 20.5 | 49 | 6.1 | --- | ---- | --- | ---- |
| -100 +200 | 531 | 66.4 | 28 | 3.5 | 160 | 20.0 | 81 | 10.1 | --- | ---- | --- | ---- |
| | | | | | Sample No. 22 | | | | | | | |
| -8 +14 | 229 | 28.6 | 314 | 39.3 | 201 | 25.1 | 45 | 5.6 | --- | ---- | 11 | 1.4 |
| -14 +28 | 438 | 54.7 | 189 | 23.6 | 101 | 12.6 | 60 | 7.5 | --- | ---- | 13 | 1.6 |
| -28 +48 | 617 | 77.1 | 96 | 12.0 | 39 | 4.9 | 45 | 5.6 | --- | ---- | 3 | 0.4 |
| -48 +100 | 634 | 79.3 | 69 | 8.6 | 40 | 5.0 | 57 | 7.1 | --- | ---- | --- | ---- |
| -100 +200 | 627 | 78.4 | 67 | 8.4 | 47 | 5.9 | 58 | 7.3 | --- | ---- | --- | ---- |
| | | | | | Sample No. 23 | | | | | | | |
| -8 +14 | 139 | 15.4 | 267 | 29.2 | 434 | 48.2 | 41 | 4.5 | --- | ---- | 20 | 2.2 |
| -14 +28 | 285 | 31.7 | 205 | 22.8 | 367 | 40.8 | 32 | 3.6 | --- | ---- | 10 | 1.1 |
| -28 +48 | 453 | 50.3 | 160 | 17.8 | 235 | 26.1 | 46 | 5.1 | --- | ---- | 6 | 0.7 |
| -48 +100 | 533 | 59.2 | 82 | 9.1 | 251 | 27.9 | 34 | 3.8 | --- | ---- | --- | --- |
| -100 +200 | 598 | 66.4 | 86 | 9.5 | 169 | 18.8 | 48 | 5.3 | --- | ---- | --- | --- |

Table II. (Cont.)

| Size Fraction | Feldspar & Quartz | | Sandstone | | Siltstone & Shale | | Misc. | | Limestone | | Chert | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Grains | % | Grains | % | Grains | % | Grains | % | Grains | % | Grains | % |
| | | | | | Sample No. 24 | | | | | | | |
| -8 +14 | 43 | 4.8 | 494 | 54.9 | 25 | 2.8 | 79 | 8.8 | 139 | 15.4 | 120 | 13.3 |
| -14 +28 | 266 | 29.6 | 248 | 31.6 | 19 | 2.1 | 90 | 10.0 | 147 | 16.3 | 94 | 10.4 |
| -28 +48 | 368 | 40.9 | 230 | 25.6 | 32 | 3.5 | 115 | 12.8 | 131 | 14.6 | 23 | 2.6 |
| -48 +100 | 405 | 45.0 | 203 | 22.6 | 64 | 7.1 | 113 | 12.5 | 111 | 12.3 | 5 | 0.5 |
| -100 +200 | 444 | 49.3 | 249 | 27.7 | 100 | 11.1 | 39 | 4.3 | 68 | 7.6 | --- | ---- |
| | | | | | Sample No. 25 | | | | | | | |
| -8 +14 | 69 | 6.3 | 595 | 54.1 | 28 | 2.5 | 56 | 5.1 | 270 | 24.5 | 83 | 7.5 |
| -14 +28 | 206 | 18.7 | 542 | 49.3 | 29 | 2.6 | 53 | 4.8 | 164 | 14.9 | 118 | 10.7 |
| -28 +48 | 334 | 31.4 | 437 | 39.7 | 45 | 4.1 | 51 | 4.6 | 186 | 16.9 | 36 | 3.3 |
| -48 +100 | 447 | 40.6 | 411 | 37.4 | 45 | 4.1 | 23 | 2.1 | 152 | 13.8 | 22 | 2.0 |
| -100 +200 | 702 | 63.8 | 270 | 24.5 | 47 | 4.3 | 23 | 2.1 | 55 | 5.0 | 3 | 0.3 |

* Sample No. 1*

| | mica | |
|---|---|---|
| -8 +14 | 19 | 0.9 |
| -14 +28 | 84 | 4.0 |
| -28 +48 | 99 | 4.7 |
| -48 +100 | 82 | 3.9 |
| -100 +200 | 155 | 7.4 |

Sample No. 2*

| | mica | |
|---|---|---|
| -8 +14 | -- | --- |
| -14 +28 | 11 | 0.5 |
| -28 +48 | 17 | 0.8 |
| -48 +100 | 77 | 3.5 |
| -100 +200 | 55 | 2.5 |

In the silt portion of the -200 mesh size fractions, quartz, feldspar, calcite, and dolomite were the constituents common to most samples. The -10 micron fractions generally contained quartz, calcite, dolomite, illite, and chlorite. Nearly all the -200 mesh fractions contained both illite and chlorite in the -4 micron clay portion. Table III lists the results of this qualitative analysis.

The quantitative analysis of the -200 mesh fractions showed that most of the fractions contained from 3% to 12% mica and clay. Exceptions were Samples 18, 19, 20, 21, 23 and 25, which ranged from 14.5 percent mica and clay in Sample 23 to 24.7 percent mica and clay in Sample 20. Percentages of silt and mica-like minerals in each -200 mesh size fraction are given in Table IV.

Table III. Qualitative Analysis of -200 Mesh Size Fractions

include the ~~whole~~ $> 10\mu$ — all $< 10\mu$ — all $< 4\mu$

| | Fraction | Quartz | Feldspar | Calcite | Dolomite | Chlorite | Illite |
|---|---|---|---|---|---|---|---|
| #1* | silt | X | X | | | X | |
| | $-10\mu$ | X | | | | | X |
| | $-4\mu$ | | | | | | X |
| #2* | silt | X | X | | | X | |
| | $-10\mu$ | X | X | | | X | X |
| | $-4\mu$ | | | | | | X |
| #3 | silt | X | X | X | | | |
| | $-10\mu$ | X | X | X | | | |
| | $-4\mu$ | | | X | | | X |
| #4 | silt | X | X | | X | | |
| | $-10\mu$ | X | X | | X | | |
| | $-4\mu$ | | | | | X | X |
| #5 | silt | X | X | X | X | X | X |
| | $-10\mu$ | X | X | X | X | X | X |
| | $-4\mu$ | | | X | | | X |
| #6 | silt | X | X | | | X | X |
| | $-10\mu$ | X | X | | | X | X |
| | $-4\mu$ | | | | | X | X |
| #7 | silt | X | X | X | X | X | X |
| | $-10\mu$ | X | X | X | X | X | X |
| | $-4\mu$ | | | X | | X | X |
| #8 | silt | X | X | X | X | X | X |
| | $-10\mu$ | X | X | X | X | X | X |
| | $-4\mu$ | | | | | X | X |
| #9 | silt | X | X | X | X | | |
| | $-10\mu$ | X | X | X | X | X | X |
| | $-4\mu$ | | | X | X | X | X |
| #10 | silt | X | X | X | X | | |
| | $-10\mu$ | X | X | X | X | | |
| | $-4\mu$ | | | X | X | X | X |
| #11 | silt | X | X | X | X | X | X |
| | $-10\mu$ | X | | X | X | X | X |
| | $-4\mu$ | | | | | X | X |

Table III. (continued)

| | Fraction | Quartz | Feldspar | Calcite | Dolomite | Chlorite | Illite |
|---|---|---|---|---|---|---|---|
| #12 | silt | X | X | X | X | X | X |
| | -10μ | X | | X | X | X | X |
| | -4μ | | | X | | X | X |
| #13* | silt | X | | | | | |
| | -10μ | X | | | | | X |
| | -4μ | | | | | | X |
| #14* | silt | X | | X | X | | |
| | -10μ | X | | X | X | | |
| | -4μ | | | X | X | | X |
| #15 | silt | X | | X | X | | |
| | -10μ | X | | X | X | X | X |
| | -4μ | | | X | | X | X |
| #16 | silt | X | | X | X | X | X |
| | -10μ | X | | X | | X | X |
| | -4μ | | | | | X | X |
| #17 | silt | X | | | | | |
| | -10μ | X | | | | X | X |
| | -4μ | | | | | X | X |
| #18 | silt | X | X | X | X | | |
| | -10μ | X | | X | | X | X |
| | -4μ | | | | | X | X |
| #19 | silt | X | | X | X | | |
| | -10μ | X | | X | X | X | X |
| | -4μ | | | X | X | X | X |
| #20 | silt | X | X | X | X | X | X |
| | -10μ | X | X | X | X | X | X |
| | -4μ | | | | | X | X |
| #21 | silt | X | X | X | X | X | X |
| | -10μ | X | X | X | | X | X |
| | -4μ | | | | | X | X |
| #22 | silt | X | X | | | X | X |
| | -10μ | X | | | | X | X |
| | -4μ | | | | | X | X |

Table III. (continued)

| | Fraction | Quartz | Feldspar | Calcite | Dolomite | Chlorite | Illite |
|---|---|---|---|---|---|---|---|
| #23 | silt | X | X | | X | X | X |
| | -10μ | X | | | X | X | X |
| | -4μ | | | | | X | X |
| #24 | silt | X | X | X | X | X | X |
| | -10μ | X | | X | X | X | X |
| | -4μ | | | X | | X | X |
| #25 | silt | X | X | X | X | X | X |
| | -10μ | X | | X | X | X | X |
| | -4μ | | | X | X | X | X |

---

* -4 micron portion contains kaolinite; Samples 1 and 2 also contained muscovite in the silt portion.

Table IV. Silt and Clay Contents of the -200 Mesh Size Fractions

| Sample No. | % mica & clay (-4μ) | % silt (+4μ) |
|---|---|---|
| 1 | 10.5 | 88.4 |
| 2 | 3.8 | 94.8 |
| 3 | 7.8 | 91.5 |
| 4 | 5.8 | 93.6 |
| 5 | 8.3 | 91.0 |
| 6 | 7.7 | 91.5 |
| 7 | 6.4 | 92.8 |
| 8 | 5.8 | 93.5 |
| 9 | 10.1 | 89.1 |
| 10 | 8.8 | 90.4 |
| 11 | 10.6 | 88.9 |
| 12 | 3.7 | 95.3 |
| 13 | 11.0 | 88.2 |
| 14 | 12.7 | 86.5 |
| 15 | 11.5 | 87.8 |
| 16 | 13.6 | 84.8 |
| 17 | 5.3 | 94.2 |
| 18 | 14.9 | 84.5 |
| 19 | 18.4 | 80.9 |
| 20 | 24.7 | 74.9 |
| 21 | 22.5 | 76.9 |
| 22 | 8.0 | 91.5 |
| 23 | 14.5 | 84.8 |
| 24 | 7.4 | 91.9 |
| 25 | 18.1 | 81.4 |

## B. Visual Description of Samples

Sample No. 1: In the (-3/8 +4) and (-4 +8) mesh fractions, the quartz pebbles were yellow in color. Some were smooth surfaces, while others showed pitting; all were irregularly shaped. define Amphiboles, pyroxenes, feldspars and micas appeared in some of the granite and gneiss pebbles. Quartz was the main constituent of the miscellaneous classification. quantity? Red and brown varieties of shale appeared in small quantities. The sand was a yellow color in the (-8 +14) to (-48 +100) mesh fractions, and grains of mica were noticeable in all fractions. The grains in the coarser sizes were angular. They became more equidimensional and rounded in the finer fractions. Dark gray grains, which could be sandstone and shale, were observed in the larger sizes. This dark portion of the sample became black in the finer sizes; this may have been caused by a change in the mineralogical composition of the grains.

Sample No. 2: Nearly all the sample was classified as miscellaneous rocks. In the (-3/8 +4) and (-4 +8) sizes, most of the miscellaneous subfraction was quartzite; appears to a few quartz pebbles were noted. The remainder of the miscellaneous subfraction was largely biotite, hornblende and garnet; most of the pebbles which pebbles? contained two or more of these minerals in aggregate form. Nearly all pebbles were angular and rough surfaced. In the larger sizes of the (-8 +14) to (-48 +100) mesh ranges, the sand exhibited a dark green appearance which changed to a light brown color in the finer fractions.

<u>Sample No. 3</u>: More than half the limestones in the (-3/8 +4) and (-4 +8) mesh sizes were relatively light in color. Approximately half of these pebbles were smooth surfaced and rounded; the remainder were angular and rough surfaced. The miscellaneous rocks were largely quartzite. They were somewhat equidimensional but very rough surfaced. There was a small amount of mica in these sizes. The coarser fractions in the (-8 +14) to (-48 +100) size ranges were blue-gray in color which changed to brown in the finer sizes. In these coarser fractions, the majority of grains were angularly shaped; they became more equidimensional in the finer sizes. Magnetite was a notable portion of miscellaneous minerals in the finer fractions. This sand contained a large percentage of feldspar.

<u>Sample No. 4</u>: The (-4 +8) size fraction was nearly all angular pebbles with very rough surfaces. The majority of miscellaneous particles consisted of quartz and quartzite. In the (-8 +14) to (-48 +100) size ranges, the color changed from brown to yellow as the grains decreased in size. These grains became more rounded and equidimensional in the finer fractions where the majority of miscellaneous minerals were quartz. but quartz is tabulated separately

<u>Sample No. 5</u>: In the (-3/8 +4) and (-4 +8) sizes, the majority of sandstones indicated some carbonate content. Most of these pebbles were somewhat elongated, rounded, and smooth surfaced. The miscellaneous particles were largely quartz and quartzite; all of which were

rounded but rough surfaced. The (-8 +14) to (-48 +100) sizes exhibited a gray brown color in the coarser fractions, which graded to a light-brown color in the finer fractions. These grains possessed some roundness.

relative % of each

Sample No. 6: In the (-4 +8) fraction, red and black varieties of shale were noted. Some of the sandstones contained muscovite. Most of them were angular and rough surfaced. The miscellaneous subfraction consisted largely of quartzite and quartz; many quartz grains contained biotite and hornblende. Several pieces of an unidentified glassy substance were also observed. Nearly all the miscellaneous pebbles were angular and rough surfaced. In the (-8 +14) to (-48 +100) size ranges, the color varied from a gray-brown to a brown as the grains became smaller. In this range, the larger grains were somewhat disc shaped; the smaller sizes were more equidimensional.

Sample No. 7: Approximately half the pebbles in the (-4 +8) fraction were rounded — the remainder were angular. An appreciable percentage of sandstones indicated carbonate content. The miscellaneous category was largely quartz and quartzite. Nearly all the miscellaneous particles were angularly shaped and rough surfaced. In the (-8 +14) to (-48 +100) size ranges, the color changed from gray-brown to brown as the grains became smaller. The larger grains were generally equidimensional.

Sample No. 8: The miscellaneous particles in the (-3/8 +4) and (-4 +8) size fractions consisted of angularly-shaped, rough-surfaced pebbles of quartz and quartzite. In general, the grains in the siltstone-sandstone subfraction were smooth-surfaced; they appeared to be a very fine-grained, calcite-bonded sandstone some of which contained mica. A green-brown color was noted in all fractions in the (-8 +14) to (-48 +100) size range. The larger sizes exhibited an irregularly shaped character while the smaller sizes were more equidimensional and rounded.

Sample No. 9: Quartz, quartzite, and granite pebbles comprised a majority of the miscellaneous species in the (-3/8 +4) and (-4 +8) size fractions. Most of these pebbles were angular and rough surfaced. The siltstones were generally rounded and smooth. Approximately half of the define limestone subfraction consisted of smooth, rounded pebbles. The remainder were irregularly shaped. Light and dark varieties of limestones as well as dolomite pebbles were in this subfraction. In the (-8 +14) to (-48 +100) size ranges, the sand graded from light-gray in the larger fractions to light brown in the smaller fractions. Blocky, irregularly-shaped grains predominated in the coarser sizes while, in the smaller fractions, the grains were more equidimensional. define equidimension?

Sample No. 10: The (-4 +8) mesh size consisted largely of angular pebbles; a large percentage of which was limestone. In the limestone subfraction, black, fine-grained and brown, coarser-grained types were noted. Most of the limestones were angular and rough surfaced. More

than half the sandstone was angular and rough surfaced. The majority of miscellaneous particles were quartz and quartzite. Nearly all of these miscellaneous rocks were irregularly shaped and very rough surfaced. In the larger fractions (-8 +14) to (-48 +100), the sand appeared blue-gray; this was caused by a large percentage of limestone. This color graded to brown in the finer fractions. The larger grains in this range were irregularly shaped; they became more equidimensional in the smaller sizes.

<u>Sample No. 11:</u> The (-3/8 +4) and (-4 +8) size fractions were nearly all sandstone; of approximately equal parts of a red and a brown variety. Most of these sandstones were angular and rough surfaced. The majority of sandstones indicated some carbonate content. Most of the miscellaneous rocks were angular and rough surfaced. The limestones generally were smooth and rounded. In the (-8 +14) to (-48 +100) size range, the coarser fractions exhibited a reddish-brown color which became more red as grain size decreased. This color was largely caused by the high percentage of sandstone present. In this size range, irregular rough-surfaced grains predominated; however, in the smaller fractions, the particles became equidimensional and quite well rounded.

<u>Sample No. 12:</u> In the (-3/8 +4) and (-4 +8) mesh sizes, red and brown varieties of sandstone comprised most of the fractions. While all the sandstones were rough surfaced, approximately half of the pebbles were rounded; the remainder were angular. Most of these sand-

stones indicated carbonate content probably as bonding material. The miscellaneous rocks were largely rough surfaced and angular; the majority of them were quartzite. The limestones were relatively pure. Approximately half were rounded and smooth surfaced. As grain size decreased in the (-8 +14) to (-48 +100) size ranges, the color changed from gray to gray brown. The larger grains were somewhat flat in shape, but they possessed little roundness. The grains became more equidimensional in the finer fractions.

Sample No. 13: In the (-4 +8) size fraction, approximately half the sandstones were rounded; all had rough surfaces. These sandstones were coarse grained, and both red and brown varieties were noted. The miscellaneous grains were largely quartz and quartzite which exhibited rough surfaces and irregular shapes. Nearly all the limestones were smooth and rounded. In the (-8 +14) to (-48 +100) size ranges, the color graded from yellow green to yellow brown as the grain size decreased. The grains became more equidimensional in the finer sizes.

Sample No. 14: In the (-3/8 +4) and (-4 +8) mesh sizes, more than half the sandstones were angular, and all of them had rough surfaces. Both red and brown varieties of sandstones were observed. The majority of sandstones indicated a carbonate content. The limestone pebbles were generally smooth surfaced and rounded. Most of the miscellaneous rocks were quartzite pebbles that were irregularly shaped and very rough surfaced. A small amount of a light-green sandstone was

present in the (-4 +8) size fraction. A color gradation from gray brown in the larger sizes to light brown in the smaller sizes was noted in the (-8 +14) to (-48 +100) size ranges. The grains were quite angular in the coarser sizes; they became more equidimensional in the finer sizes.

Sample No. 15: In the (-4 +8) size fraction, nearly all the sandstones were angular and rough surfaced. Red, brown, and buff varieties of sandstone were noted; the majority of sandstones indicated some carbonate present. The majority of siltstones were well rounded, equidimensional and smooth surfaced. Nearly all the siltstones also indicated the presence of carbonates. Angular, rough-surfaced pebbles were common in the limestone subfraction which contained a notable amount

first place mentioned

of dolomite. The miscellaneous fragments were all angular and had rough surfaces. In the (-8 +14) to (-48 +100) size ranges, a color gradient from blue gray to gray brown was noted as grain size decreased; the blue-gray color was caused by the large percentage of limestone present. Angular grains, exhibiting some flatness, were common in the larger sizes. The grains became more equidimensional in the smaller sizes.

Sample No. 16: In the (-3/8 +4) and (-4 +8) mesh sizes, the siltstone portion was found to be composed of smooth-surfaced, well-rounded, disc-shaped particles; a small amount of which contained carbonate. In general, the sandstones had well-rounded edges, relatively smooth surface textures, and were gray in color. There was a small

amount of relatively soft clay — containing sandstones and a lesser portion that were calcite bonded. A smooth surface texture and dirty color were noted in the limestones, with some dolomite present in the limestone subfraction. The majority of the particles in the miscellaneous portion were irregularly shaped and rough surfaced with the exception of the quartz grains. In the (-8 +14) to (-48 +100) mesh ranges, the color graded from a gray to a gray brown from coarse to fine particle sizes. The grains appeared flattened with rounded corners in the coarser sizes while, in the finer fractions, the particles became more equidimensional and rounded. White grains appeared in the coarser sizes and became quite noticeable in the finer size fractions.

Sample No. 17: Brown sandstone constituted a major part of the (-4 +8) size fraction. Most of these sandstones were angular while the remainder were well rounded; all exhibit rough surfaces. The siltstone portion contained an appreciable amount of soft brown shale. Irregular grains with variable surface textures were noted in the miscellaneous subfraction. A yellow-brown color which graded to yellow in the finer fractions was observed in the (-8 +14) to (-48 +100) mesh ranges. The larger grains were angular, while more equidimensional and rounded particles were noted in the smaller size fractions.

Sample No. 18: In the (-3/8 +4) mesh sizes, the pebbles in the sandstone portion had fairly smooth surfaces. About half were irregular in shape, and the remainder were nearly equidimensional. Nearly

all the sandstone indicated carbonate content. Included in the sandstone subfraction were several calcite-bonded aggregates of smaller grains ($\sim$ 30 mesh). Both brown and black shales, disc shaped and rounded, were noted in the siltstone portion. Most of the remaining siltstones were smooth surfaced and nearly equidimensional. Approximately half of the siltstone subfraction indicated carbonate content. The miscellaneous grains were largely quartz, quartzite, and chlorites; most of these were angular, and the surface texture was variable. In the (-8 +14) to (-48 +100) mesh ranges, the grains appeared flattened with rounded edges; they became more equidimensional in the finer fractions. The sand color graded from gray in the coarser sizes to brown in the finer fractions.

Sample No. 19: The sandstone in the (-4 +8) mesh fraction consisted generally of well-rounded pebbles with relatively smooth surfaces. Irregular shapes and varying surface textures characterized the pebbles in the miscellaneous category which were largely quartzite. In the (-8 +14) to (-48 +100) size ranges, limestone was visible by its blue-gray color. In the smaller-sized fractions, a high percentage of quartz imparted a white color to the sand. In general, the larger grains in this range were well rounded; they became more equidimensional as particle size decreased. A gray color noted in the larger fractions graded to light brown in the smaller sizes.

Sample No. 20: In the (-3/8 +4) and (-4 +8) mesh sizes, the majority of sandstones were angular, rough surfaced and gray in color. Most of them indicated carbonate content. The pebbles in the miscellaneous and limestone portions were nearly all angular and rough surfaced. The miscellaneous species were largely quartz and quartzite. Rounded edges and smooth surfaces characterized the grains in the siltstone subfraction. A color gradient of gray to brown from coarse to fine particle size was noted in the (-8 +14) to (-48 +100) size ranges. Irregularly shaped grains, some well rounded and others with sharp edges, were present in the coarser sizes. Most of the pebbles were angular in the finer fractions.

Sample No. 21: The siltstone portion of the (-3/8 +4) and (-4 +8) mesh fractions consisted of rounded, smooth-surfaced pebbles. The shale particles, gray in color, were somewhat disc shaped. Angular, rough-surfaced grains were common in the sandstone, limestone and some of the miscellaneous pebbles. Some of the siltstones and sandstones indicated carbonate content. In the (-8 +14) to (-48 +100) size ranges, the color graded from gray brown to light brown with a decrease in grain size. Particles of dark shale were noticeable in the larger fractions of this range. The larger grains within this range appeared somewhat flattened and round edged. The smaller sizes were more equidimensional.

Sample No. 22: Pebbles having an irregular shape but smooth surface were common in the siltstone portion of the (-3/8 +4) and (-4 +8)

fractions. A black variety of shale was most common. The shale particles were somewhat disc shaped and rounded. Most of the sandstones were rounded and fairly smooth surfaced; the remainder were angular and rough surfaced. The miscellaneous fragments, whose major constituent was quartzite, were generally angularly shaped and rough surfaced. In the (-8 +14) to (-48 +100) mesh size ranges, a color gradient from green brown to light brown was noted as grain size decreased. In this size range, the harder particles in the coarse fractions were more angular than the softer grains. Rounded, equidimensional grains comprised a notable percentage of the finer grains.

<u>Sample No. 23:</u> In the (-3/8 +4) and (-4 +8) size fractions, the siltstone subfraction consisted of rounded, smooth-surfaced grains. A gray variety of shale was present in disc-shaped pebbles. Rough surfaces and angular shapes characterized the grains in the sandstone portion; the few limestones noted were smooth and rounded. A majority of miscellaneous particles exhibited irregular shapes and rough surfaces; their major constituents were mica schists, gneisses, and quartzite. The larger grains in the (-8 +14) to (-48 +100) size range were generally rounded; the smaller fractions were more angular but equidimensional. A gray-brown to brown color gradient with decrease in grain size was noted.

<u>Sample No. 24:</u> In the (-3/8 +4) and (-4 +8) mesh sizes, nearly all the sandstones and siltstones were rounded, slightly elongated, and

smooth surfaced. The majority of limestones were smooth, rounded, and blue gray in color. The miscellaneous subfraction consisted largely of irregularly shaped pebbles of variable surface texture. The sand color changed from gray to gray brown as particle size decreased in the (-8 +14) to (-48 +100) mesh ranges. All grains in these size ranges were notably equidimensional; they became more rounded as mesh size decreased.

Sample No. 25: The sandstone pebbles in the (-3/8 +4) and (-4 +8) mesh sizes were generally smooth and rounded. The remainder were angular and rough surfaced. Most of the siltstones were rounded and smooth, and many indicated a carbonate content. The majority of limestones were smooth surfaced; some were angularly shaped. The miscellaneous pebbles exhibited both smooth and rough surfaces, and they were generally irregularly shaped. A color change from gray to brown occurred as the particle size decreased within the (-8 +14) to (-48 +100) mesh ranges. Flat, angular grains were notable in the coarser sizes; but in the finer sizes, they became more rounded and equidimensional.

### C. Roundness and Sphericity Measurements

The average sphericities of the grains examined in the (-14 +28) mesh size fractions were found to be in a range from 0.68 to 0.77. A range of b/a values from 0.69 to 0.80 was noted with the c/b ratios occurring in a range of 0,55 to 0.79.

Most of the sphericity values were in the 0.6 to 0.9 range. Sample 18 had 70% of the particles in this range, and Sample 10 had 96% in this range. The 0.7 to 0.8 sphericity range contained from 31 to 50 percent of the grains. An exception was Sample 18 in which 39% of the grains had sphericity values of 0.6 to 0.7.

Table V gives the average b/a, c/b and sphericity values for each (-14 +28) mesh fraction. The distribution of sphericity values is shown for each sample in Figures 3 through 27.

Roundness averages ranged from 33.1 in Sample 20 to 55.7 in Sample 24. From 66% to 85% of the grains observed had roundness values in the 33 to 66 range. Table VI lists the number of grains in each roundness group together with the average roundness for each sample.

D. Acid Insoluble Residue of Limestone

The amount of acid insoluble residue in the limestone portions analyzed ranged from 5.9% in Sample 9 to 40.4% in Sample 13. Table VII gives the insoluble residue percentages for each of the 16 portions tested.

End of card.

Table V. Average Values of b/a, c/b and Sphericity for 100 Grains in (-14 +28) Size Fraction

Surface Area of containing sphere

| Sample No. | b/a | c/b | Sphericity |
|---|---|---|---|
| 1 | 0.80 | 0.70 | 0.75 |
| 2 | 0.74 | 0.73 | 0.73 |
| 3 | 0.76 | 0.79 | 0.77 |
| 4 | 0.76 | 0.72 | 0.74 |
| 5 | 0.80 | 0.73 | 0.77 |
| 6 | 0.69 | 0.78 | 0.74 |
| 7 | 0.76 | 0.66 | 0.72 |
| 8 | 0.77 | 0.71 | 0.74 |
| 9 | 0.76 | 0.67 | 0.72 |
| 10 | 0.76 | 0.71 | 0.73 |
| 11 | 0.74 | 0.66 | 0.70 |
| 12 | 0.73 | 0.72 | 0.72 |
| 13 | 0.77 | 0.66 | 0.72 |
| 14 | 0.73 | 0.66 | 0.70 |
| 15 | 0.74 | 0.72 | 0.73 |
| 16 | 0.76 | 0.69 | 0.73 |
| 17 | 0.76 | 0.71 | 0.73 |
| 18 | 0.72 | 0.55 | 0.68 |
| 19 | 0.74 | 0.64 | 0.70 |
| 20 | 0.73 | 0.62 | 0.68 |
| 21 | 0.75 | 0.65 | 0.71 |
| 22 | 0.76 | 0.74 | 0.74 |
| 23 | 0.75 | 0.66 | 0.71 |
| 24 | 0.78 | 0.68 | 0.74 |
| 25 | 0.73 | 0.63 | 0.69 |

Table VI. Average Roundness of Grains in (-14 +28) Size Fraction

| Sample No. | No. of Grains in Roundness Group 0 | 33 | 66 | 100 | Average Roundness |
|---|---|---|---|---|---|
| 1 | 24 | 54 | 18 | 4 | 33.7 |
| 2 | 19 | 40 | 29 | 12 | 44.3 |
| 3 | 23 | 53 | 17 | 7 | 35.7 |
| 4 | 9 | 38 | 35 | 18 | 53.6 |
| 5 | 8 | 35 | 39 | 18 | 55.3 |
| 6 | 15 | 42 | 31 | 11 | 45.3 |
| 7 | 17 | 38 | 34 | 11 | 46.0 |
| 8 | 16 | 38 | 34 | 12 | 47.0 |
| 9 | 23 | 49 | 17 | 11 | 38.4 |
| 10 | 17 | 49 | 26 | 8 | 41.3 |
| 11 | 5 | 60 | 25 | 10 | 46.3 |
| 12 | 9 | 48 | 21 | 22 | 51.7 |
| 13 | 20 | 57 | 18 | 5 | 35.7 |
| 14 | 7 | 50 | 35 | 8 | 47.6 |
| 15 | 20 | 51 | 21 | 8 | 38.7 |
| 16 | 14 | 39 | 37 | 10 | 47.3 |
| 17 | 15 | 51 | 26 | 8 | 42.0 |
| 18 | 8 | 49 | 28 | 15 | 49.7 |
| 19 | 10 | 46 | 29 | 15 | 49.3 |
| 20 | 28 | 50 | 16 | 6 | 33.1 |
| 21 | 11 | 49 | 34 | 6 | 44.6 |
| 22 | 9 | 56 | 29 | 6 | 43.6 |
| 23 | 14 | 48 | 30 | 8 | 43.6 |
| 24 | 6 | 46 | 22 | 26 | 55.7 |
| 25 | 23 | 49 | 22 | 6 | 36.7 |

Table VII. Percent of Acid Insoluble Residue of Limestone Portions from (-3/8 +4) and (-4 +8) Size Fractions

| Sample No. | Percent Acid Insoluble Residue |
|---|---|
| 3 | 9.0 |
| 5 | 19.7 |
| 7 | 18.0 |
| 8 | 20.3 |
| 9 | 5.9 |
| 10 | 7.8 |
| 11 | 12.3 |
| 12 | 18.3 |
| 13 | 40.4 |
| 14 | 14.3 |
| 15 | 14.0 |
| 16 | 31.2 |
| 19 | 12.2 |
| 20 | 17.4 |
| 24 | 12.0 |
| 25 | 11.2 |

## IV. Discussion of Results

The results of this analysis indicated that Samples 1, 2, 3, 4 and 10 should be suitable for use as aggregate in concrete. Samples 1, 2, 3 and 4 appeared favorable due to their high quartz and feldspar content and negligible amounts of shale, siltstone, and sandstone. A substantial amount of stable miscellaneous rocks was also present in Sample 2 with Sample 3 having an appreciable stable-limestone content. The sandstone in Sample 4 was probably not present in a sufficient amount to cause problems. Sample 10 contained a large amount of limestone and a lesser amount of miscellaneous rocks, both of which should be stable. The sandstone, siltstone, and shale could cause trouble although they were present in an amount less than 15%.

The remaining sands were judged unsuitable because of substantial amounts of sandstone, siltstone, shale, limestone or chert.

Siltstone and shale are, of course, unsound because of their clay content, and chert, due to the basic nature of concrete. The limestone was judged stable or unstable depending on the percentage of acid-insoluble residue. An insoluble residue of less than 15% is usually indicative of a stable limestone, but other factors such as absorption and type of bedding also effect soundness and would have to be investigated in order to declare a limestone definitely unsound. It is difficult, also, to judge the stability of sandstone as other factors, such as those affecting limestone, are necessary in this type of analysis. In general, however, sandstone is unsound as a concrete aggregate.

Several variable factors were noted during the course of this analysis, the main one being a problem in definition. It was necessary to separate coarse-grained siltstone from fine-grained sandstone, limey siltstones from silty limestones and rock — or mineral — containing quartz grains from quartz-containing rock or mineral grains. In making grain counts, the magnification of the binocular microscope had to be raised to necessitate grain identification in the smaller size fractions. Discrepancies may have appeared here in that a grain appearing as a siltstone under low magnification might be identified as a sandstone under the higher power. Because of these variables, the grain counts of all the designated size fractions in a sample were done by one person to obtain consistency.

It may also be noted that in many of the coarser fractions (-3/8 +4) and (-4 +8) mesh sizes the percentages reported do not total 100 percent. This was due to the acid testing of suspected limestones, crushing of some particles for petrographic analysis or the breaking of some smooth-surfaced pebbles to examine grain size, bonding media, color, or fracture.

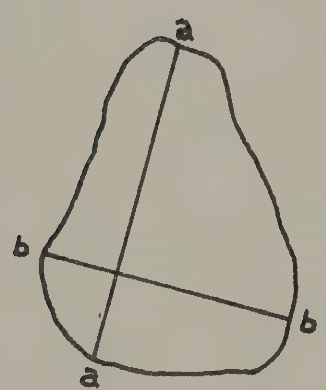
Marvin Gridley, Petrographer and Author
Gordon Bjorck, Technician
Kent Collins, Technician
Hatay Arkayn, X-ray Technician

Wayne Brownell

Wayne E. Brownell
Professor

FIGURE 1

OUTLINE OF GRAINS FOR DETERMINING SPHERICITY




MAXIMUM
PROJECTION AREA


MINIMUM
PROJECTION AREA

Figure 2 Graph of b/a versus c/b for Determining Sphericity of a Particle

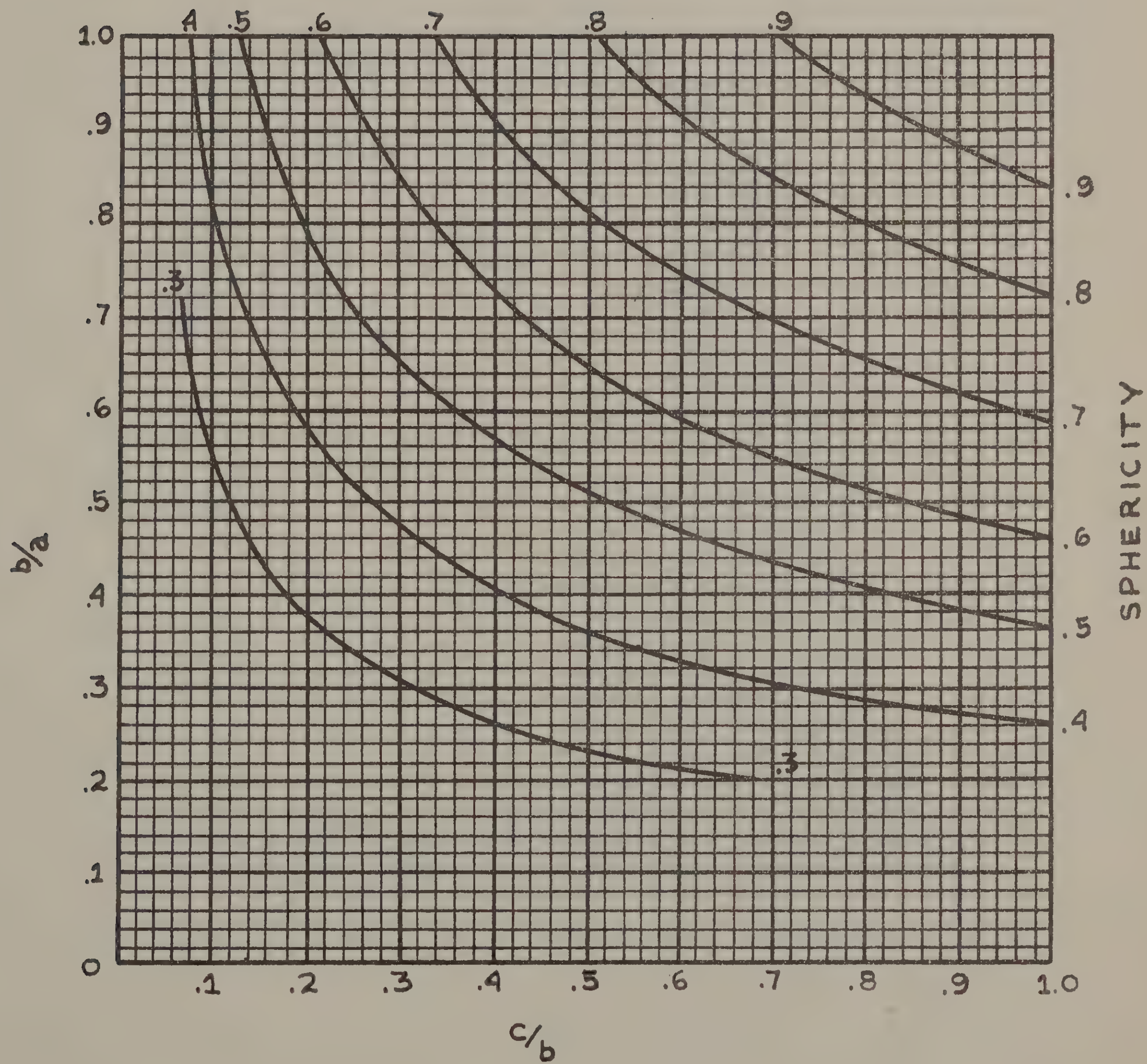


FIGURE 3

BAR GRAPH OF SPHERICITY RANGES IN SAMPLE NO. 1

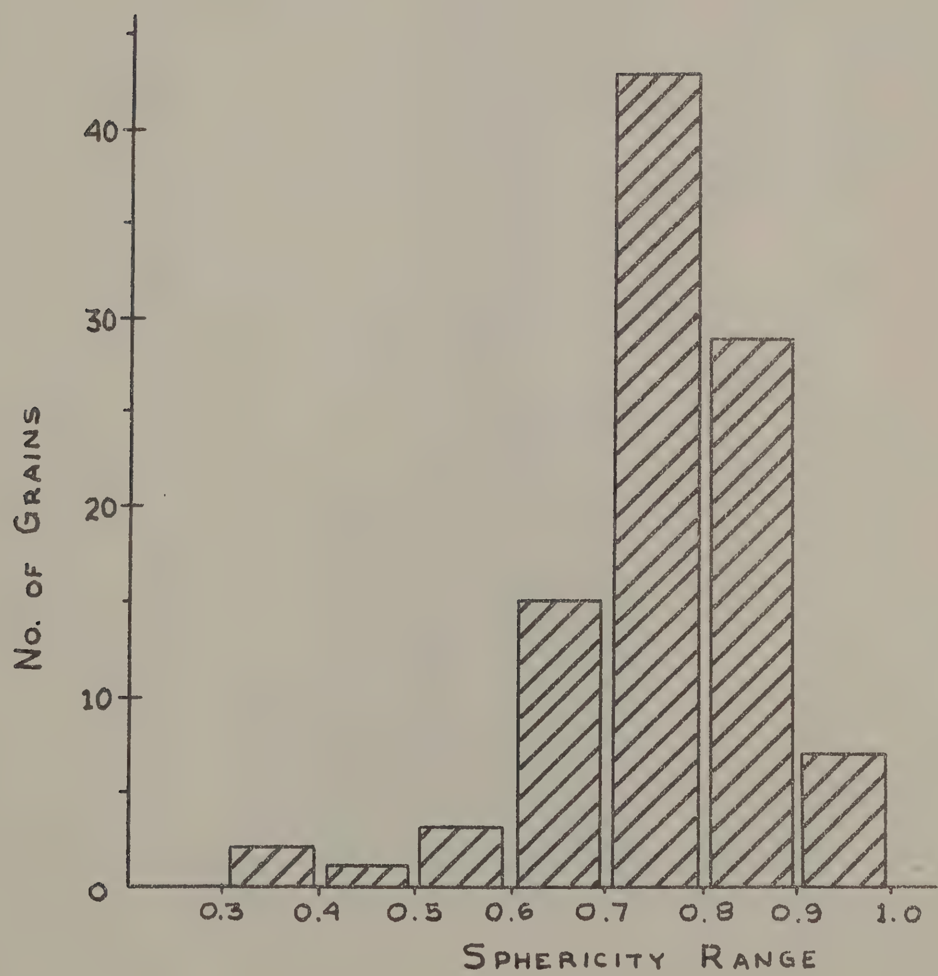


Figure 4

Bar Graph of Sphericity Ranges in Sample No. 2

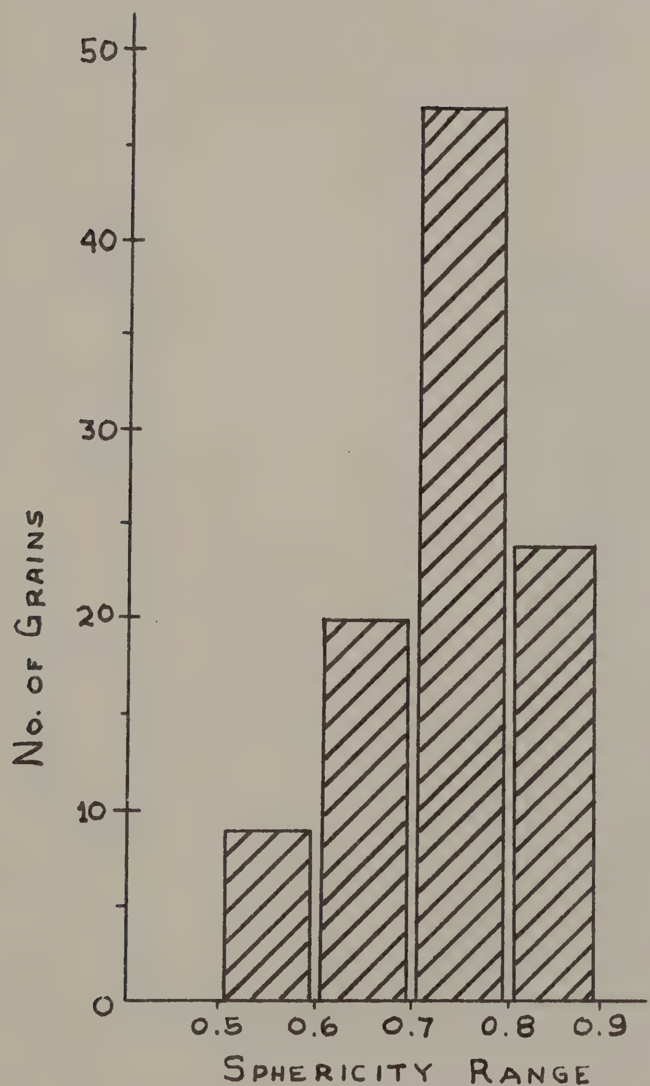


FIGURE 5

BAR GRAPH OF SPHERICITY RANGES IN SAMPLE NO. 3

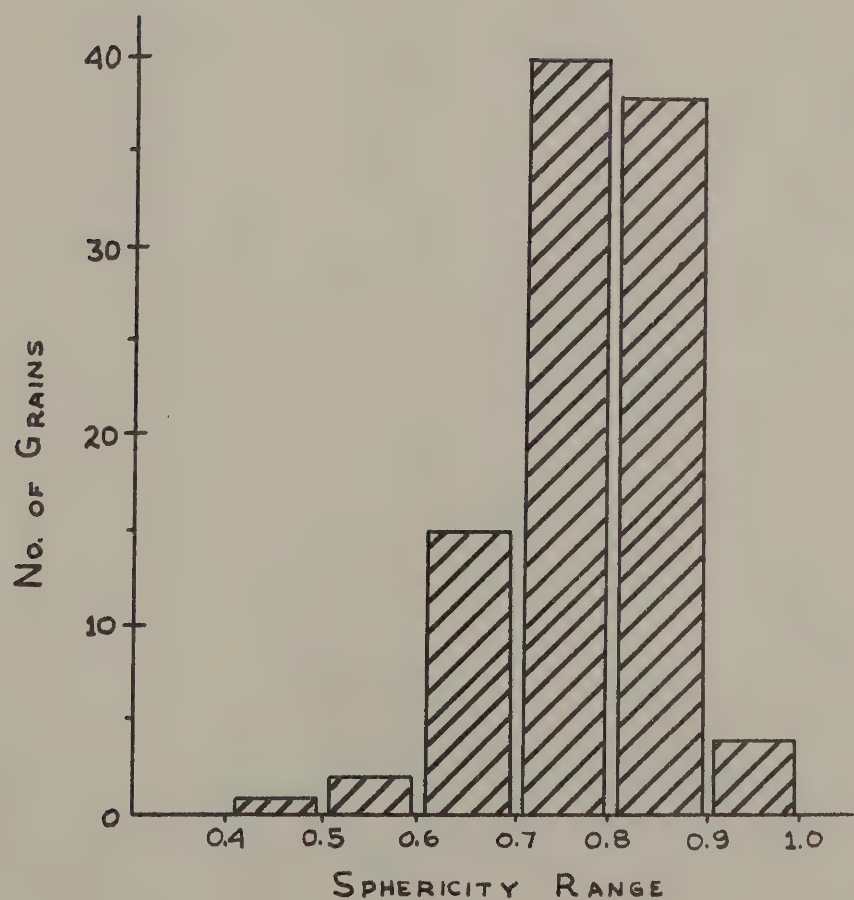


Figure 6

Bar Graph of Sphericity Ranges in Sample No. 4

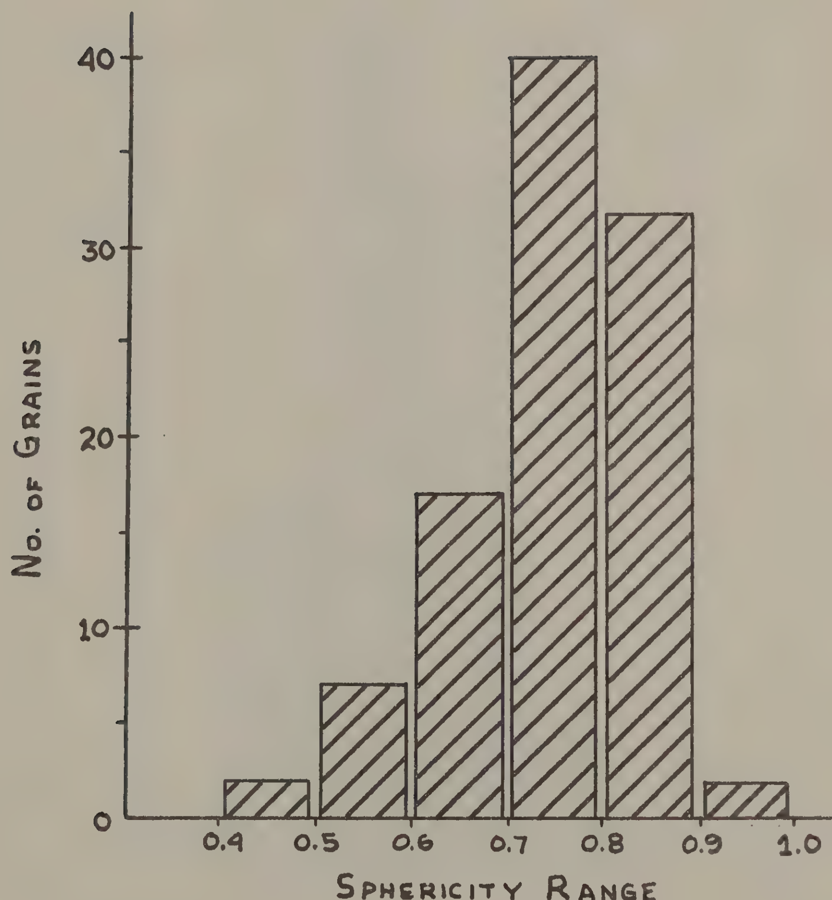


FIGURE 7

BAR GRAPH OF SPHERICITY RANGES
IN SAMPLE NO. 5

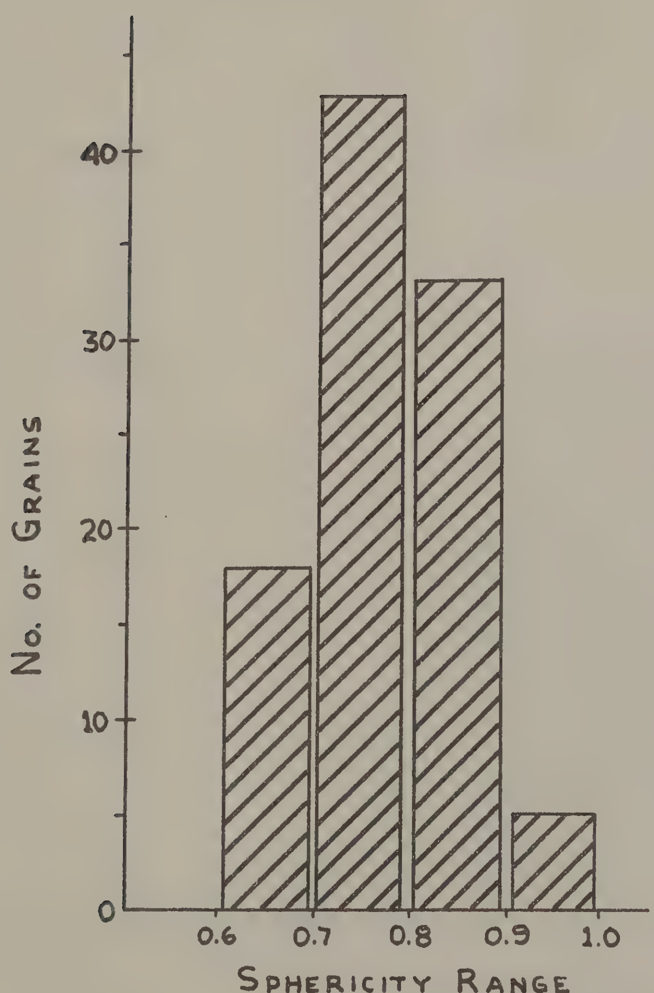


FIGURE 8

BAR GRAPH OF SPHERICITY RANGES
IN SAMPLE NO. 6

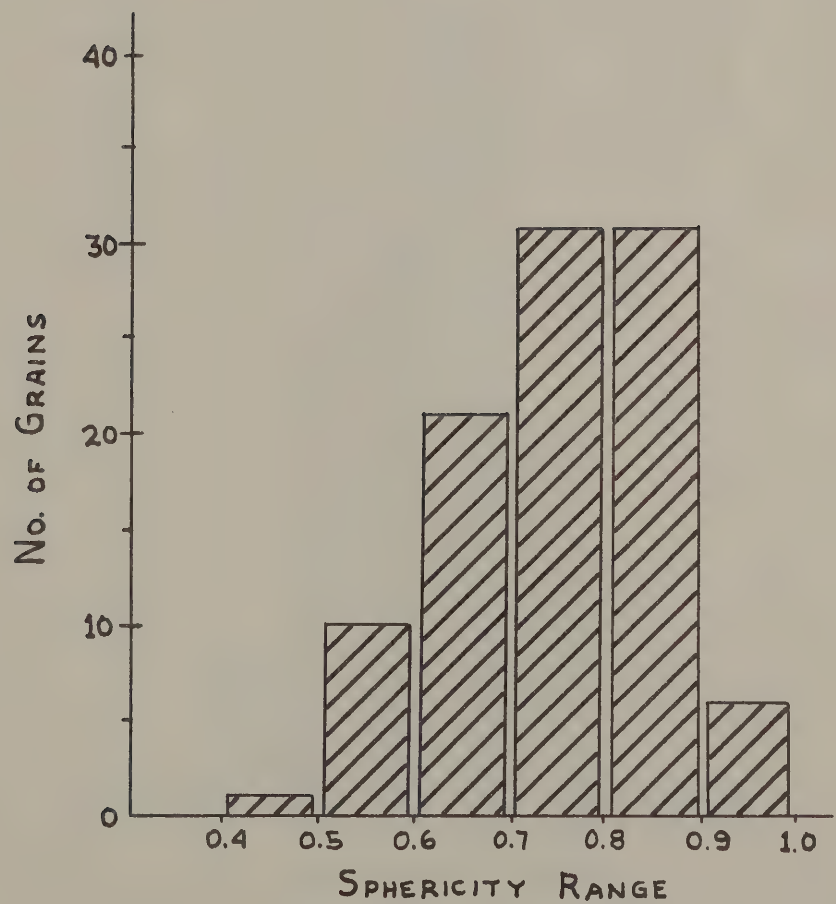


Figure 9

Bar Graph of Sphericity Ranges in Sample No. 7

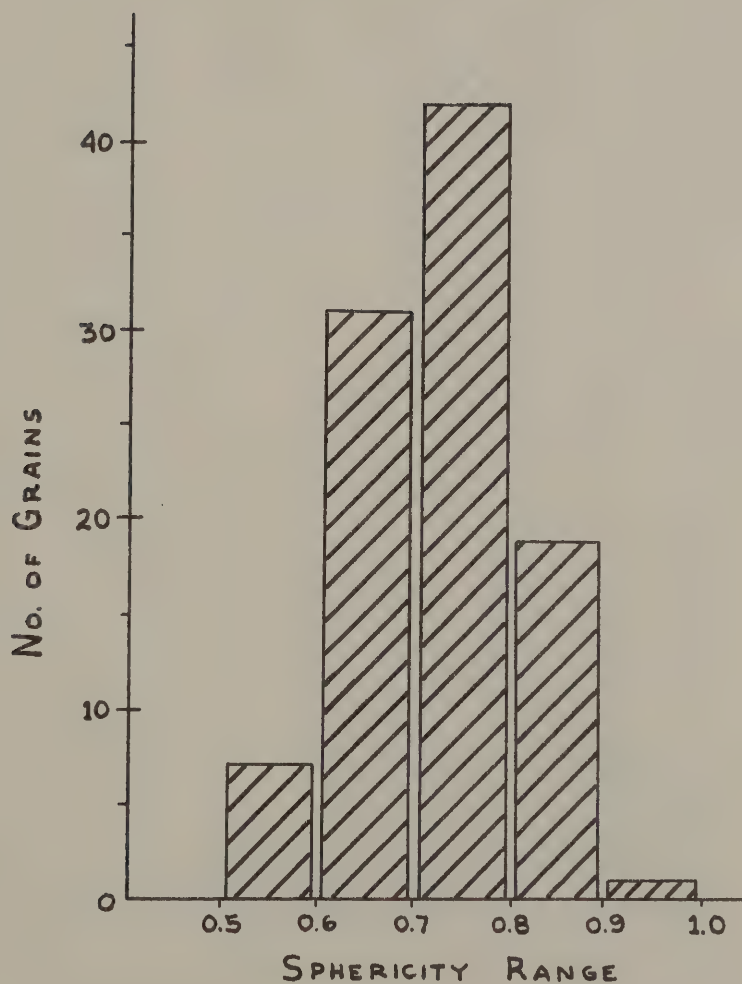


Figure 10

Bar Graph of Sphericity Ranges in Sample No. 8

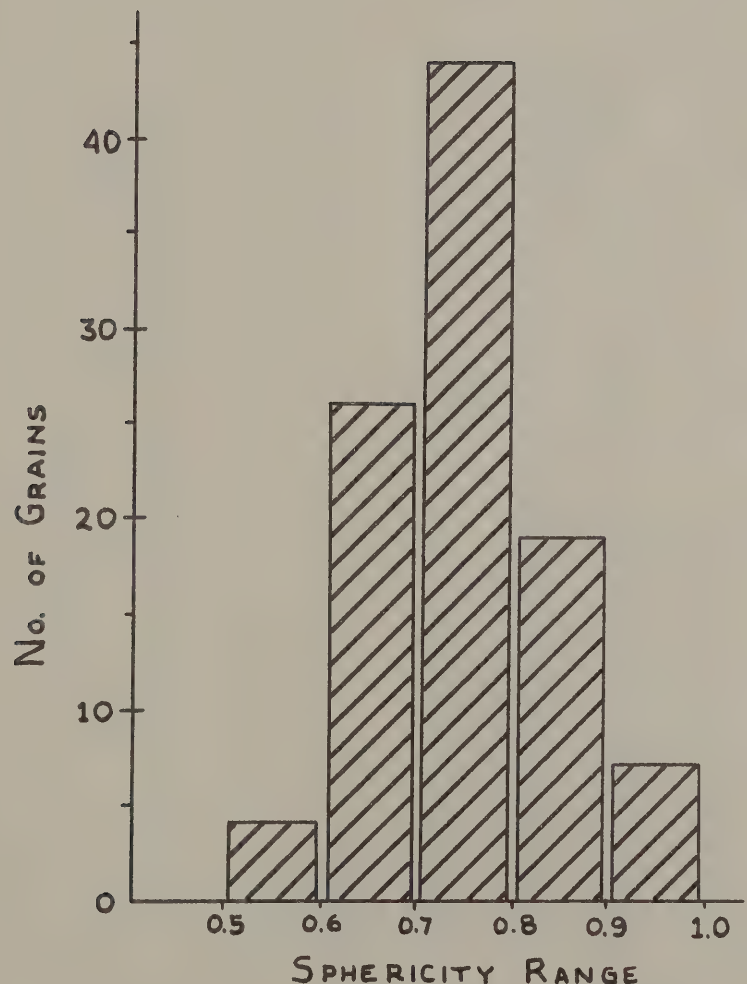


FIGURE 11

BAR GRAPH OF SPHERICITY RANGES IN SAMPLE NO. 9

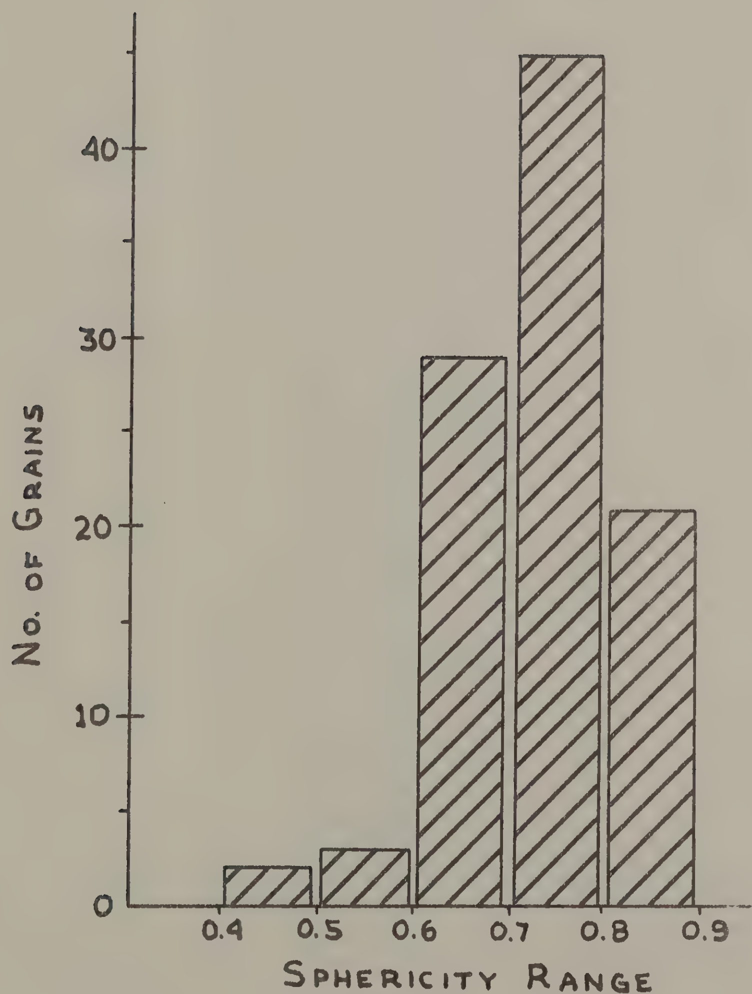


FIGURE 12

BAR GRAPH OF SPHERICITY RANGES IN SAMPLE No. 10

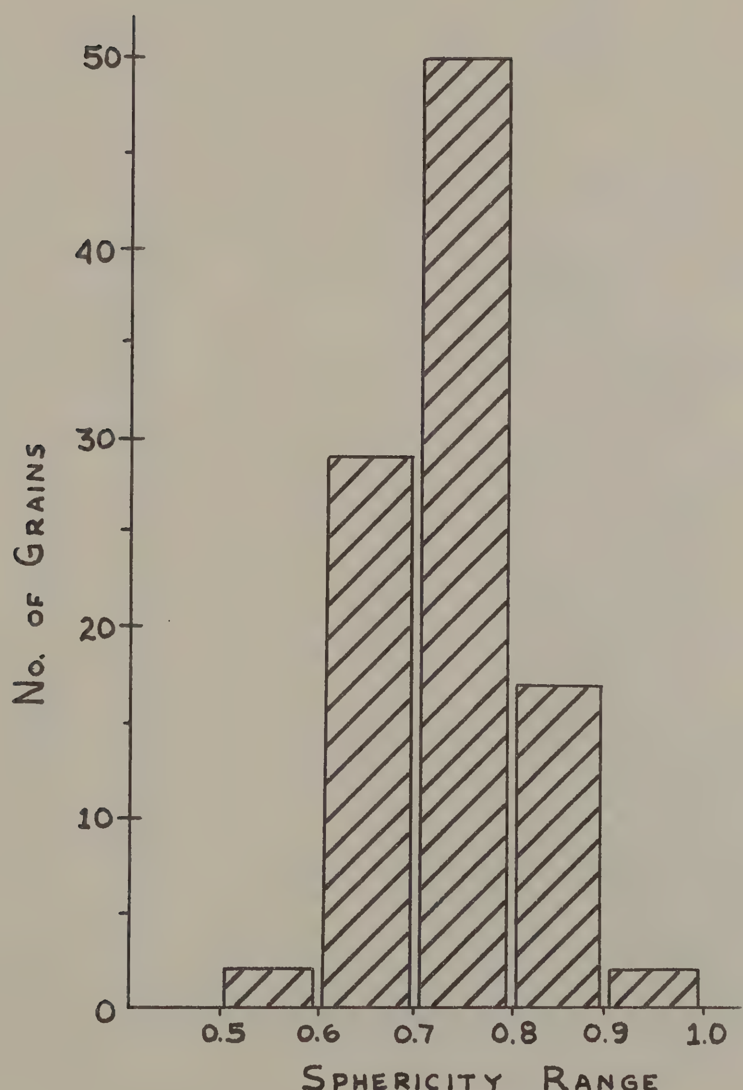


FIGURE 13

BAR GRAPH OF SPHERICITY RANGES
IN SAMPLE NO. 11

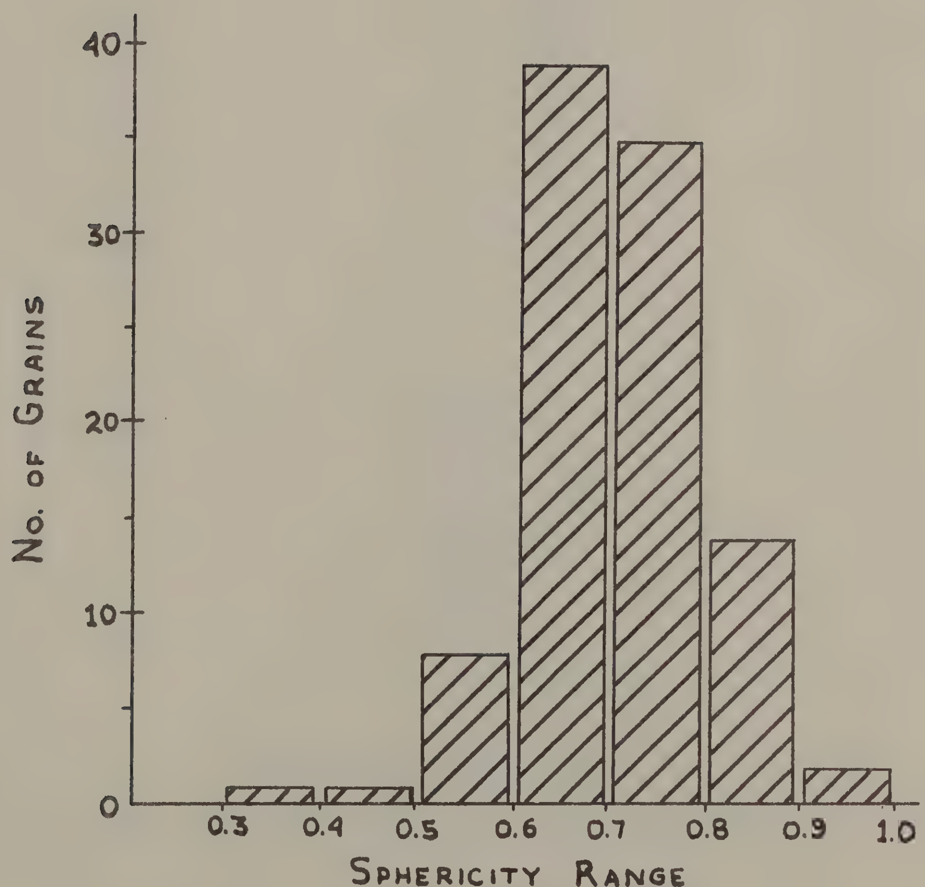


Figure 14

Bar Graph of Sphericity Ranges in Sample No. 12

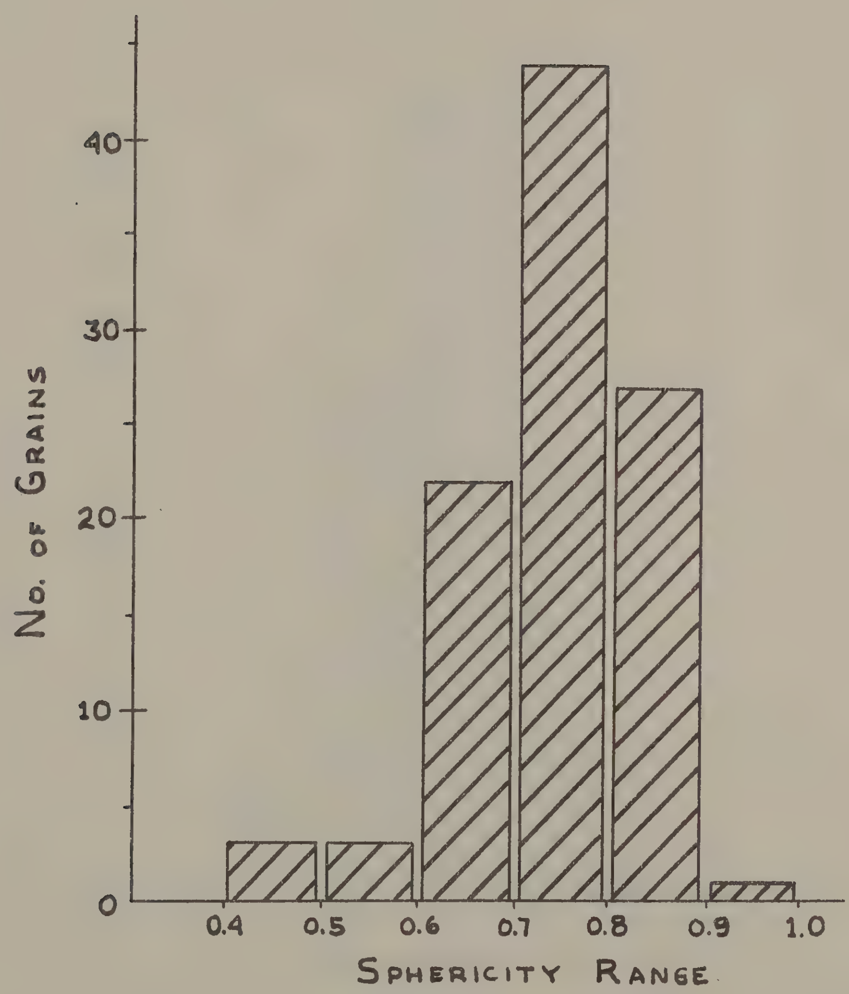


Figure 15

Bar Graph of Sphericity Ranges
in Sample No. 13

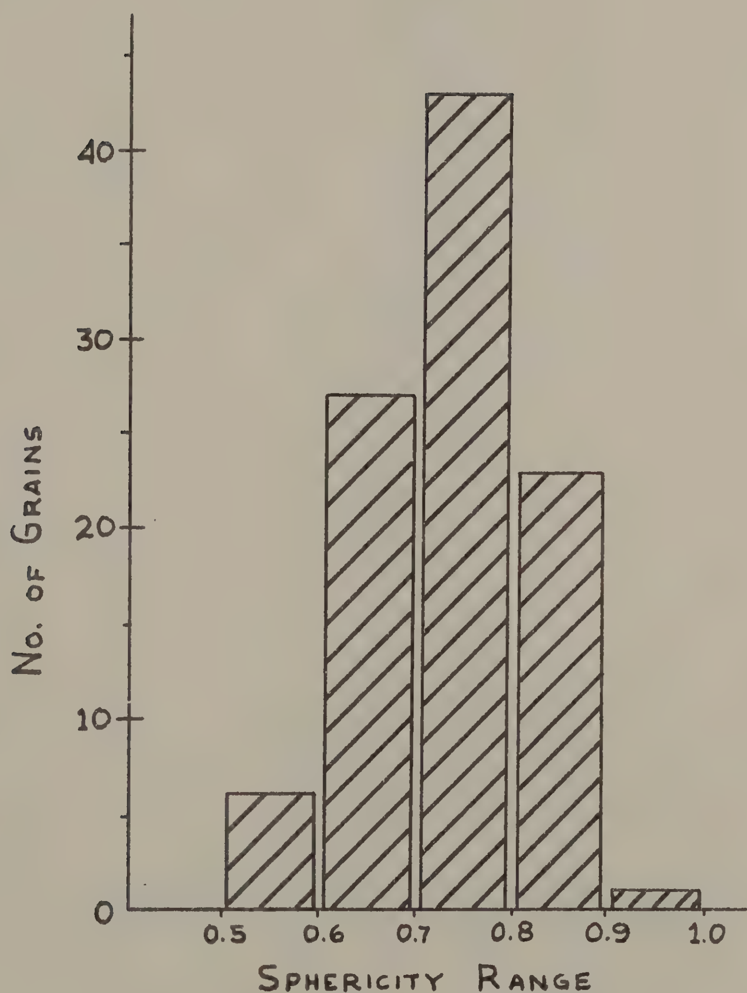


Figure 16

Bar Graph of Sphericity Ranges in Sample No. 14

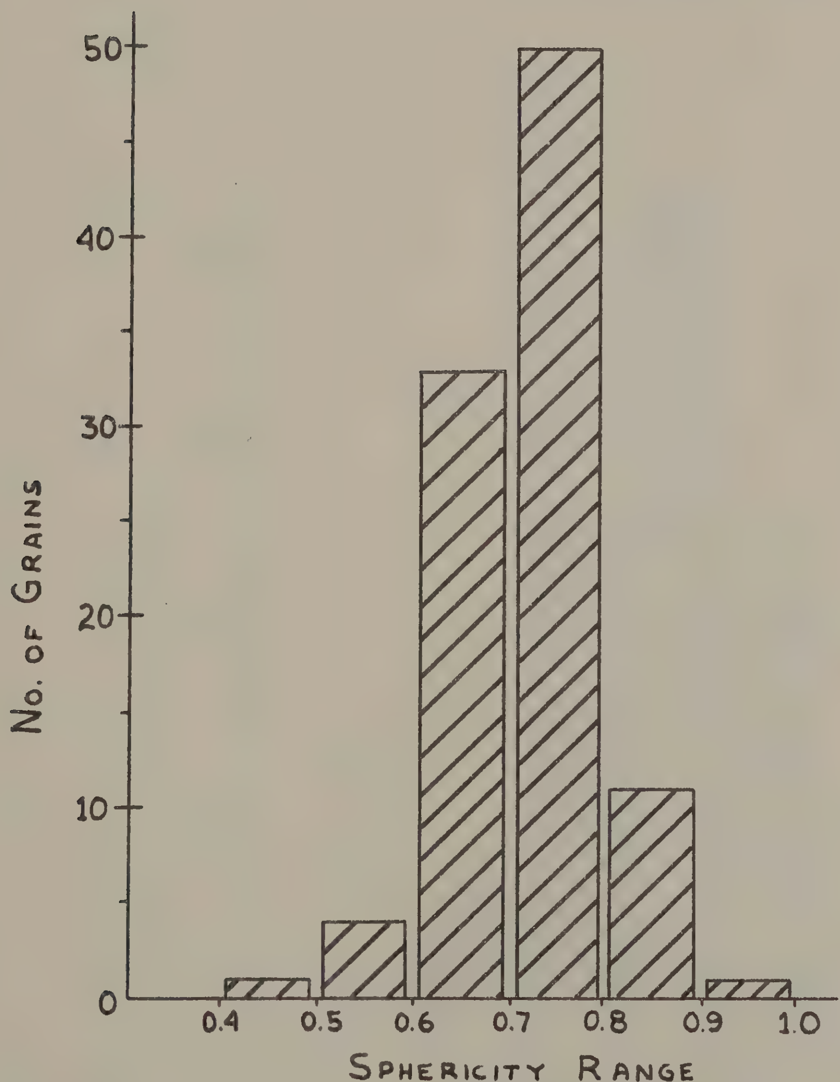


Figure 17

Bar Graph of Sphericity Ranges in Sample No. 15

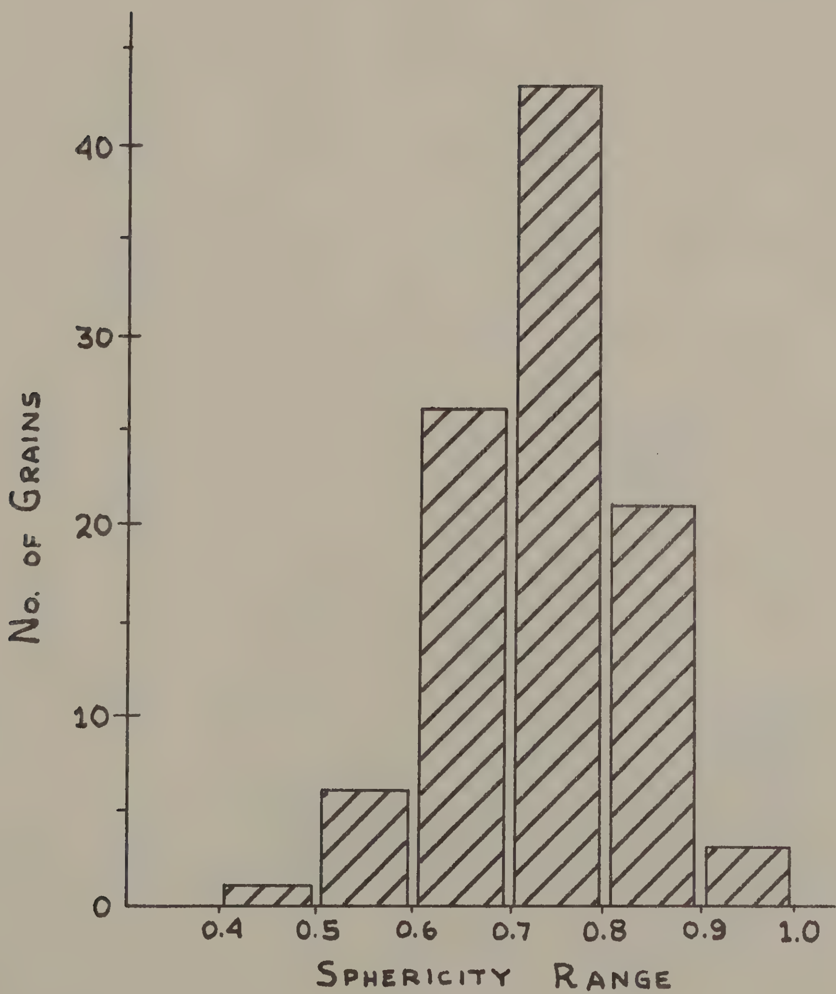


FIGURE 18 BAR GRAPH OF SPHERICITY RANGES OF SAMPLE #16

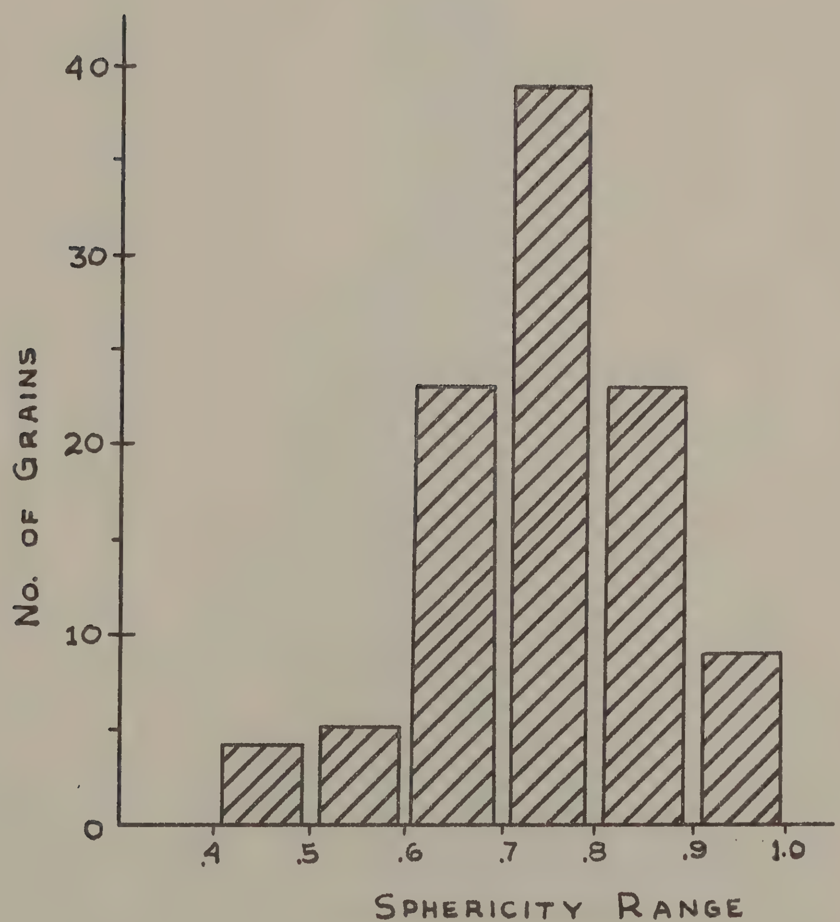


Figure 19

Bar Graph of Sphericity Ranges in Sample No. 17

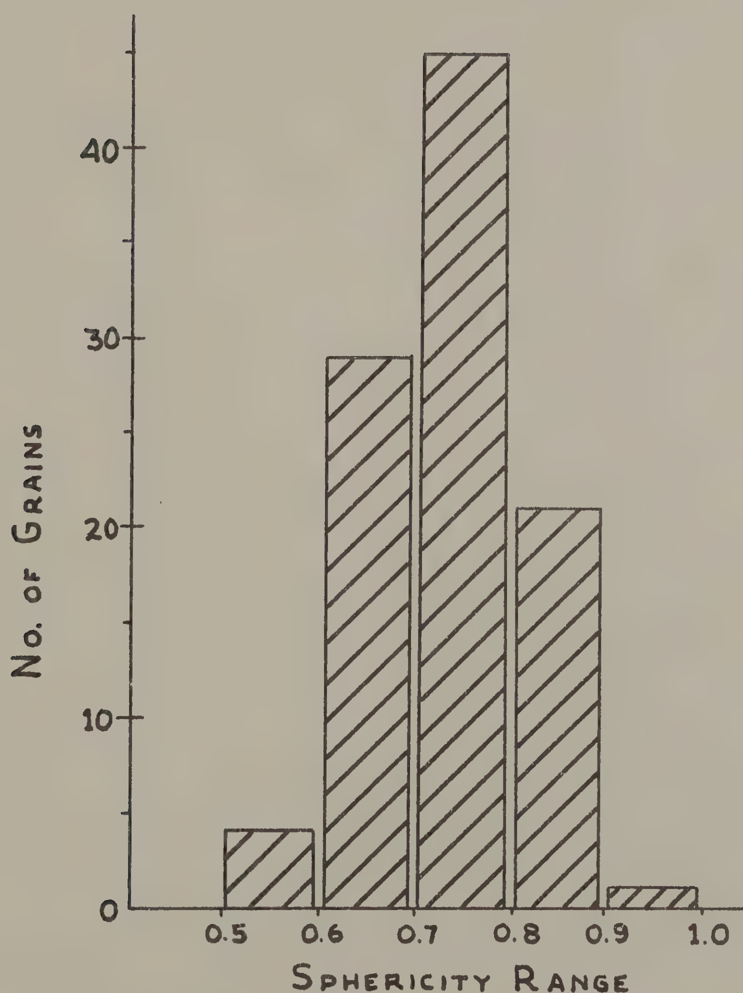


Figure 20

Bar Graph of Sphericity Ranges in Sample No. 18

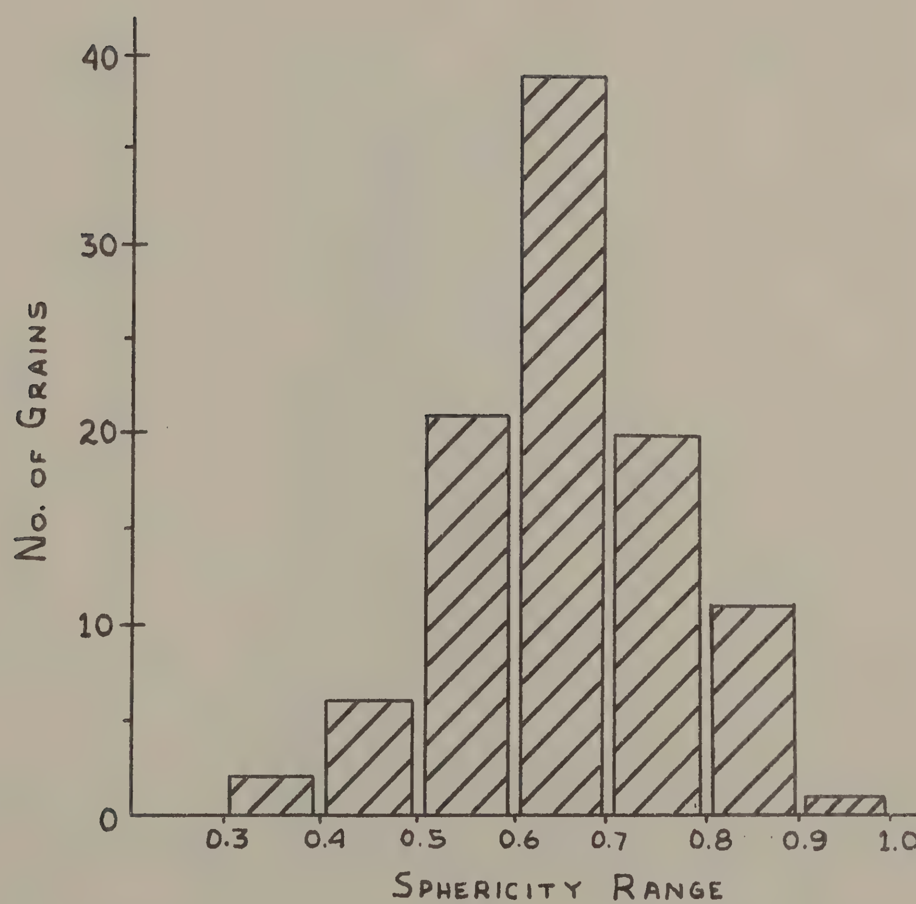


Figure 21

Bar Graph of Sphericity Ranges
in Sample No. 19

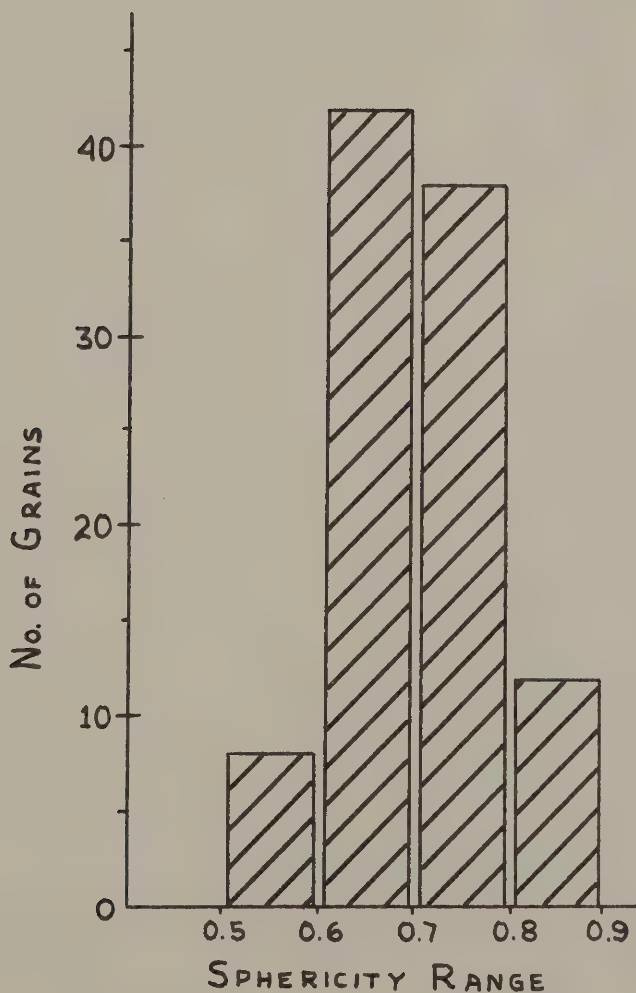


Figure 22

Bar Graph of Sphericity Ranges in Sample No. 20

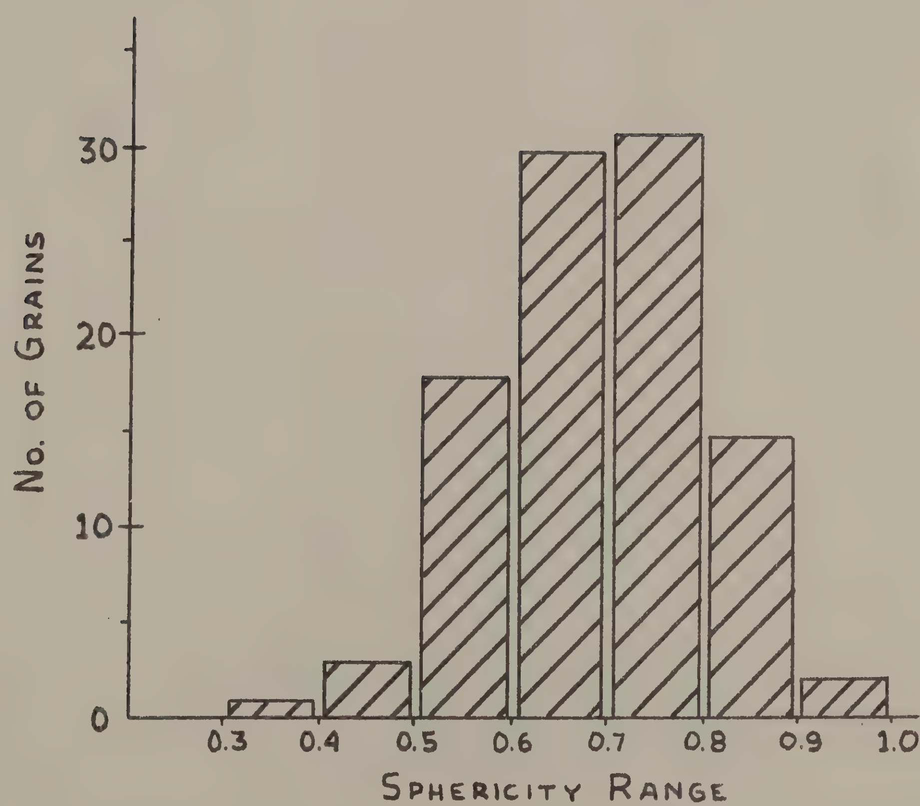


Figure 23

Bar Graph of Sphericity Ranges in Sample No. 21

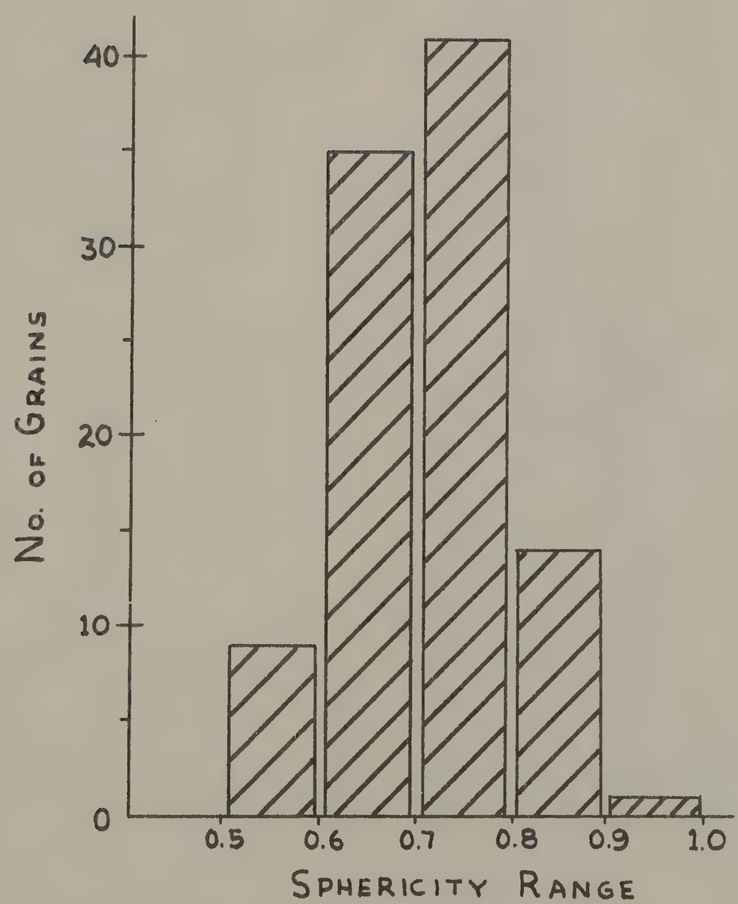


Figure 24

Bar Graph of Sphericity Ranges in Sample No. 22

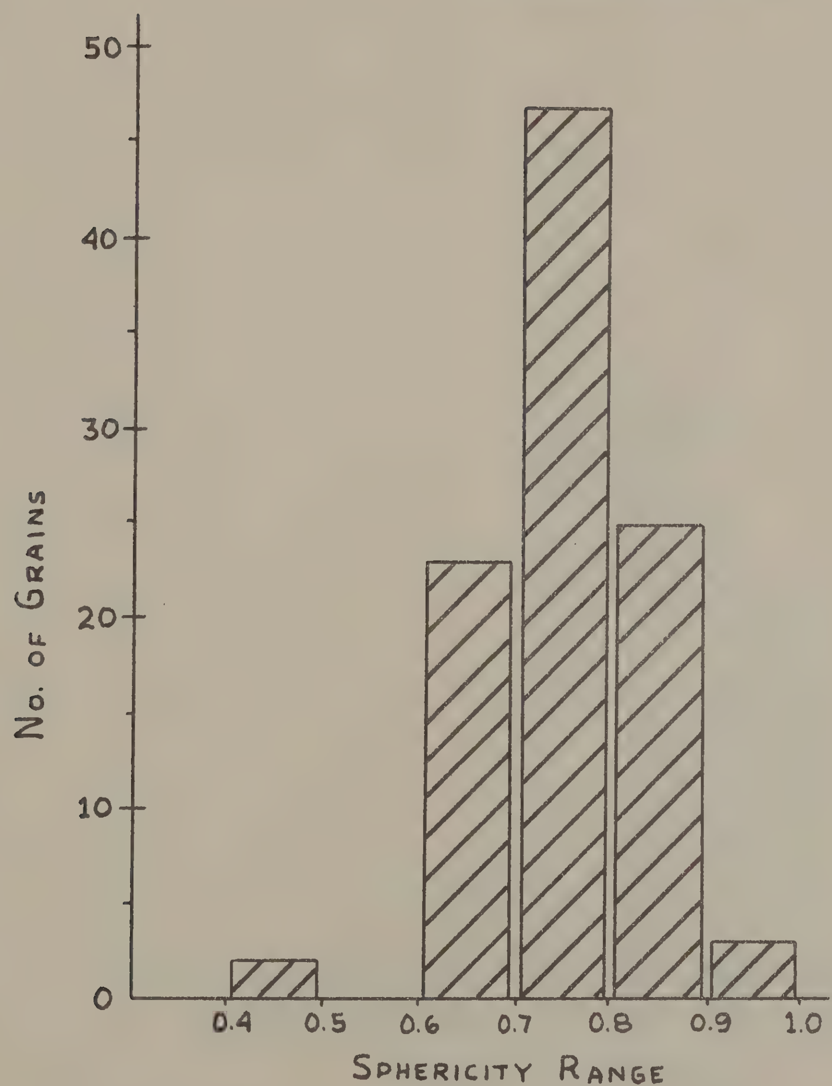


FIGURE 25

BAR GRAPH OF SPHERICITY RANGES
IN SAMPLE NO. 23

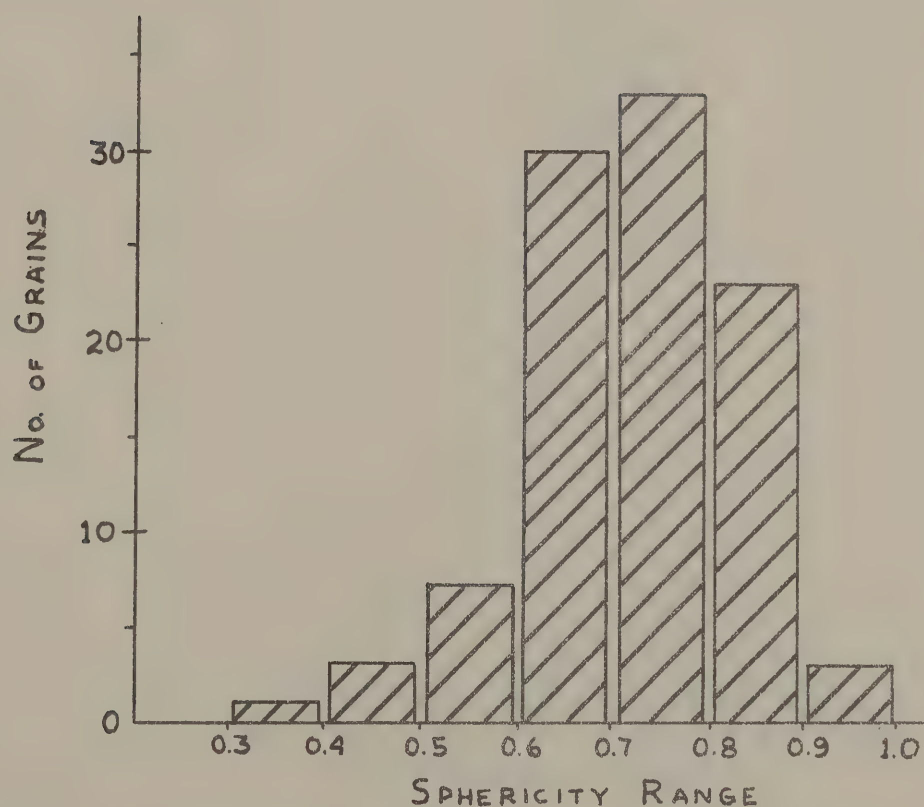


Figure 26

Bar Graph of Sphericity Ranges in Sample No. 24

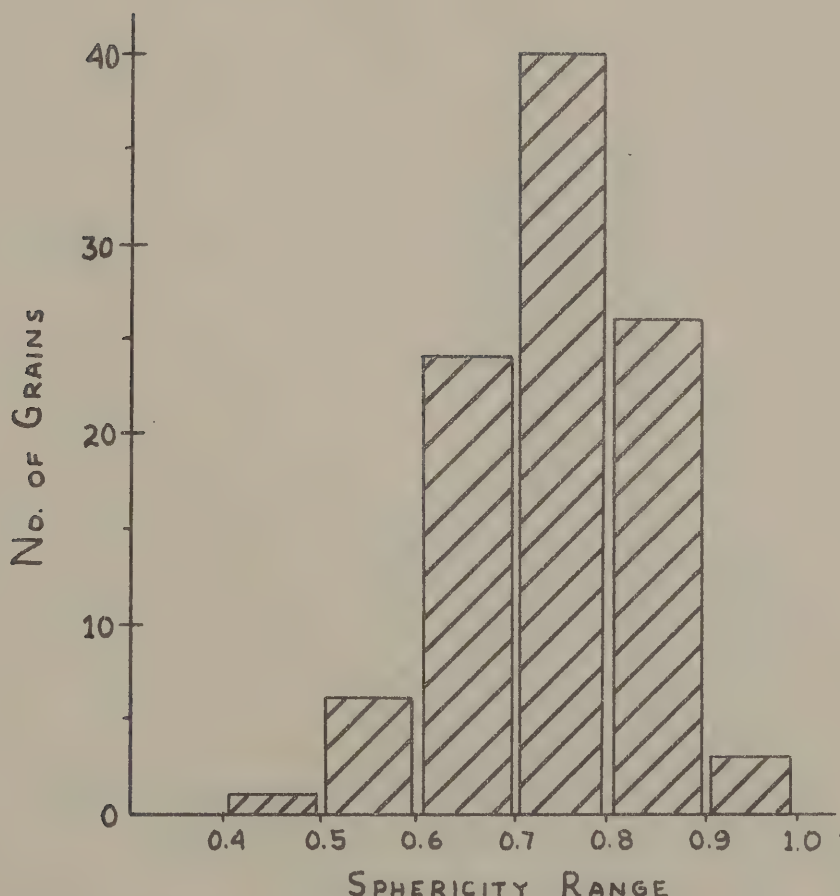


Figure 27

Bar Graph of Sphericity Ranges
in Sample No. 25